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Graduate teaching assistants' perceptions of teaching competencies required for work in undergraduate science labs

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ABSTRACT

Many post-secondary institutions provide training and resources to help GTAs fulfil their teaching roles. However, few programmes focus specifically on the teaching competencies required by GTAs who work with undergraduate students in laboratory settings where learning tends to be more active and inquiry based than in classroom settings. From a review of 8 GTA manuals, we identified 20 competencies and then surveyed faculty and lab coordinators (FIS) and GTAs from a Faculty of Science at a comprehensive Canadian university to identify which of those competencies are required of GTAs who work in undergraduate science labs. GTAs and FIS did not significantly differ in the competencies they view as required for GTAs to work effectively in undergraduate labs. But, when comparing the responses of GTAs and FIS to TA manuals, 'Clearly and effectively communicates ideas and information with students' was the only competency for which there was agreement on the level of requirement. We also examined GTAs' self-efficacy for each of the identified competencies and found no overall relationship between self-efficacy and demographic characteristics, including experience and training. Our results can be used to inform the design of training programmes specifically for GTAs who work in undergraduate science labs, for example, programmes should provide strategies for GTAs to obtain feedback which they can use to enhance their teaching skills. The goal of this study is to improve undergraduate lab instruction in faculties of science and to enhance the teaching experience of GTAs by better preparing them for their role.

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Introduction

Graduate teaching assistants (GTAs) fulfil an important role in undergraduate education in today's post-secondary institutions. Chairing seminars, facilitating discussion groups, instructing in labs, conducting demonstrations, tutoring, supervising field trips, grading, and invigilating exams are some of the many teaching-related responsibilities of GTAs.

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Since the late 1960s, efforts have been made to prepare graduate students for these teaching responsibilities (Stumpf, 1971). In 1986, a conference on *Institutional Responsibility and Responses in the Employment and Education of Teaching Assistants* marked the first national effort to address the needs of GTAs in American colleges and universities (Lewis, 1993). While many institutions have since developed training programmes and/or guides for GTAs, they have received mixed reviews about their efficacy, and there remains a perception that GTAs are unprepared for their roles (DeChenne et al., 2012; Luft, Kurdziel, Roehrig, & Turner, 2004; Shannon, Twale, & Moore, 1998). This has been partially attributed to the fact that many programmes and guides are general in nature. That is, they provide discipline-neutral instruction and advice on teaching and learning with little opportunity to develop discipline-specific pedagogical skills (Harris & McEwan, 2009; Luft et al., 2004; Park, 2004).

There is a limited body of literature about the specific teaching-related skills required by GTAs who work with undergraduate students in science, technology, engineering, and mathematics (STEM). Laboratory experiences are a regular feature in STEM programmes and, while GTAs are rarely responsible for teaching a whole course, they are responsible for the majority of instruction in laboratories: Abraham et al. (1997) in chemistry; Cho, Sohoni, and French (2010) in engineering; Goodlad (1997) in science, technology, and medicine; Spears and Zollman (1974) in physics; Sundberg, Armstrong, and Wischusen (2005) in biology. Previous work by Deacon and Hajek (2011) found that the GTAs significantly influenced undergraduates' overall satisfaction and perception of value of laboratory experiences in physics. Duties of GTAs who work in science laboratories include such activities as: conducting demonstrations, giving lectures, assisting students with conducting and understanding experimental work, facilitating group work, supervising students, ensuring lab safety, and marking lab reports. Herrington and Nakhleh (2003) explain that effective teaching in labs is different from effective teaching in traditional classroom instruction in three ways: (1) lab instruction is more interactive and one-on-one; (2) the function of the instructor in the laboratory is to help students come to an explanation that is consistent with the data, not to impose an explanation; and (3) laboratory instructors use teaching and learning strategies that are different from those used by classroom instructors. Luft et al. (2004) reported that GTAs in introductory science laboratories did not find university-wide training effective in helping them to teach in the laboratory setting.

Tigelaar, Dolmans, Wolfhagen, and Van der Vleuten (2004) define teaching competencies as 'an integrated set of personal characteristics, knowledge, skills, and attitudes that are needed for effective performance in various teaching contexts' (p. 255). Using the Delphi Method, they developed and validated a framework for teaching competencies in post-secondary education that included student-focused approaches and considered aspects of a teacher's personality. Simpson and Smith (1993) and Cho et al. (2010) conducted reviews of educational research to develop survey items for research on GTAs' roles and responsibilities. Lowman and Mathie (1993) performed a content analysis of TA manuals from across the United States to identify the most commonly occurring teaching topics. While the lists of topics or competencies are similar, there are differences and there is no comprehensive list of a GTA's potential roles and responsibilities and the required knowledge and skills to perform effectively.

Sohoni, Cho, and French (2013) administered a survey to engineering faculty members, GTAs, and students to find out what roles and responsibilities were most important in

effective engineering GTAs and to determine how competent the GTAs were in those roles. The survey consisted of 24 items related to instructional practices, classroom management, and engagement with students. They found that clear communication, and grading student work and providing useful feedback were perceived as more important than managing and dealing with student behaviours and motivation problems, and course management or knowledge of policies. Additionally, faculty and students rated GTA competence in these roles significantly lower than the GTAs rated themselves. This difference was also seen in an earlier study of the effect of training and experience on GTAs' self-perception of teaching effectiveness by Shannon et al. (1998).

Herrington and Nakhleh (2003) surveyed undergraduate students and GTAs involved in an introductory chemistry lab. Using a questionnaire with 17 statements about effective teaching, with some statements more specific to the laboratory context, they looked at what these groups considered to be important qualities for an effective lab GTA and whether they differed in their opinion. Of the eight top-rated statements for each group, six were common. The top two were: 'is well prepared for lab' and 'thoroughly understands the lab exercise'. Student responses to the free-response question asking about the qualities that are important for an effective laboratory GTA resulted in a considerable number of comments that specifically mentioned the importance of good communication skills (also noted by Deacon & Hajek, 2011).

Research on the relationship between teaching self-efficacy and training and experience has shown variable results. Based on Bandura's (1977) definition of self-efficacy as one's beliefs about their capability to produce effects, Prieto and Altmaier (1994) found that GTAs with prior training and those with previous teaching experience demonstrated higher levels of self-efficacy. Shannon et al. (1998) found that GTA self-ratings were not positively affected by either training or experience. DeChenne and Enochs (2010), who defined teaching self-efficacy as teachers' beliefs that they will be able to effectively teach a given population of students a specific subject, studied the teaching self-efficacy of GTAs in STEM. Since the STEM context is somewhat different from other teaching contexts, they adapted the College Teaching Self-Efficacy Scale developed by Prieto Navarro in 2005. Using their more context-specific instrument, they found no difference in the teaching self-efficacy between GTAs who had attended training and those who had not. DeChenne, Koziol, Needham, and Enochs (2015) found that a GTA's self-efficacy is influenced by the interaction of a variety of factors, the most significant being the departmental teaching environment (including relationships with supervisors and peers) and the quality of professional development rather than the hours spent in professional development. For international teaching assistants, Kim (2009) found that teaching experience was correlated with teaching self-efficacy related to instructional strategies and classroom management, but not those related to student engagement. They cautioned that for this group, sociocultural adaptation (i.e. knowledge and use of culturally appropriate social and communication skills) is an important predictor of perceived self-efficacy in teaching.

Research, in specific disciplines and across disciplines, has attempted to determine what form GTA training should take, what skills should be taught, and how training programmes should be evaluated. While we can borrow from existing teaching development programmes, we recognise the importance of context in good teaching and seek to address the specific skills and strategies required for effective teaching in the science laboratory. The goal of this study is to identify those strategies/competencies. The questions that

we asked relative to this goal are: (1) What teaching competencies are reflected in GTA manuals? (2) Which of these competencies do lab personnel and instructors believe to be required? (3) Which of these competencies do lab GTAs believe to be required? and (4) How do GTAs rate their ability to perform in each of the competency areas? A survey was used because it was the most efficient way to obtain information from a large number of GTAs and personnel working in laboratories. Interviews with GTAs were used to further explore the teaching experiences and competencies required for work in that context. We then use this information to make recommendations of content for training programmes for science GTAs.

Method

Survey design

We designed a survey to determine the importance to GTAs and faculty members and laboratory instructional staff, of specific teaching competencies. The competencies which formed the basis of the survey were derived from a review of GTA manuals as per the methodology used by Lowman and Mathie (1993). Hereafter, the faculty members and instructional staff are referred to as 'FIS'. Lowman and Mathie (1993) found that for most GTAs, the GTA manual is the primary written resource for help with teaching and general socialisation about the value of good teaching. We obtained online TA manuals from eight Canadian universities (four comprehensive; four medical/doctoral) and used these as a starting point to determine the teaching competencies important for GTAs working in labs. The manuals were all prepared by the institutions' centre for teaching and learning and were general in nature; that is, they were not written to provide guidelines or advice to GTAs working in a specific discipline or in a specific learning environment. Our content analysis was based on the topic of each paragraph (e.g. discussion, motivation, lesson plan). We selected one manual and together, assigned each paragraph a topic code. Using the resulting list of codes, we independently coded a second manual and refined the coding system. Sixty-three teaching-related topics were identified. All manuals were subsequently coded by one of two investigators and results for the eight manuals were combined to give an overall total occurrence of teaching-related topics.

The topics were grouped into 20 related skill areas and assigned a competency descriptive of the teaching activity. While the manuals included information on a variety of teaching and learning strategies (e.g. demonstration, use of visual material, and group work), four occurred frequently enough to justify their own individual competencies: facilitating discussion, using effective questioning strategies, providing feedback, and using examples. Skill in the use of a variety of teaching strategies is represented by a single competency, 'Uses a variety of appropriate teaching and learning strategies to help students understand material'. The competencies were randomly assigned a number from 1 to 20 and listed in numerical order in the survey. The same list was used in both the questionnaire for GTAs and the one for FIS. The competencies appear in rank order by occurrence in the manuals in Table 1.

Respondents to both questionnaires were asked to rank their top five most important competencies from the given list. These competencies were assigned a corresponding value

Table 1. Rank of occurrence of competencies in GTA manuals.

Rank	Competency
1	14. Uses a variety of appropriate teaching and learning strategies to help students understand material[abc]
2	9. Is knowledgeable about institutional, departmental and course policies and procedures, and institutional resources[a]
3	10. Develops and maintains a positive classroom atmosphere[ac]
4	6. Clearly and effectively communicates information and ideas with students[ac]
5	4. Uses self-reflection and feedback from supervisor, peers, and students to improve teaching[a]
6	12. Demonstrates concern and respect for all students[abc]
7	11. Uses fair and consistent marking strategies[abc]
8	17. Is well-prepared for teaching duties[bc]
9	1. Effectively manages personal and work time to fulfil teaching responsibilities[c]
10	2. Demonstrates a high standard of ethical and professional conduct[c]
11	13. Maintains a safe and orderly learning space[ab]
12	3. Stimulates and facilitates meaningful discussions with students[ac]
13	5. Helps students understand course expectations[a]
14	7. Effectively uses questioning strategies to promote learning[bc]
15	15. Gives frequent, regular and constructive feedback to students[abc]
16	20. Uses relevant examples to help students understand concepts[ac]
17	16. Demonstrates a high level of knowledge in the discipline[ac]
18	8. Demonstrates good presentation skills[c]
19	19. Monitors how well students are progressing with their learning and learning tasks.
20	18. Demonstrates enthusiasm for discipline[ab]

[a]Related to competency appearing in Simpson and Smith's (1993) list of 26 competencies for GTAs.
[b]Related to competency appearing in Herrington and Nakhleh's (2003) list of 17 items defining effective chemistry lab instruction.
[c]Related to competency appearing in Cho et al.'s (2010) list of 24 items describing typical GTA roles and responsibilities.

from one to five, with five being the highest-ranked competency. The sum for each competency was then calculated.

Respondents were also asked to indicate, for each of the 20 competencies, the degree to which they agreed or disagreed with the statement that the competency was required for GTAs. Response options consisted of a five-point Likert scale with 'Strongly disagree' (1) and 'Strongly agree' (5) as anchor points. For example:

This competency is required for GTAs to work effectively in undergraduate labs in my discipline.					
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. Effectively manages personal and work time to fulfil teaching responsibilities	○	○	○	○	○

The GTAs' mean rating of importance for each competency was compared to that of the FIS using a *t*-test.

The GTA questionnaire also asked respondents to indicate their level of skill in each competency with 'Not at all skilled' (1) and 'Expert' (5) as anchor points. For example:

	Not at all skilled	Some skill	Moderately skilled	Good level of skill	Expert
1. Effectively manages personal and work time to fulfil teaching responsibilities	○	○	○	○	○

The GTAs' mean rating of importance for each competency was compared to the rating of their skill in that competency, again using a *t*-test.

The questionnaire for FIS asked respondents to identify any additional competencies required by GTAs that were not included in our list.

The GTA survey obtained information on various characteristics of the GTAs (Table 2). Three of these were used in further analysis: first language (English vs. Other), previous semesters as a GTA (0–2 semesters vs. 3 or more semesters), and amount of teacher preparation (No preparation vs. all the other categories). The GTAs' mean rating of importance and rating of their skill in each competency were compared for each of these three characteristics using *t*-tests.

The survey also asked GTAs to provide their name and email address if they were willing to be interviewed about their work in undergraduate labs.

Administration and participation

The questionnaires were constructed in and administered using the Survey tool in Desire2Learn™, the institution's learning management system. They were made available to FIS and GTAs in the following disciplines at one comprehensive Canadian university: biochemistry, biology, chemistry, computer science, earth science, math and statistics, physics, and psychology.

For the FIS group, 23 laboratory instructional staff members were identified from departmental staff lists and invited by email to take part. At the study institution, laboratory staff are responsible for instructing and supervising GTAs. The laboratory instructional staff were also asked to suggest faculty members who were familiar with the

Table 2. GTA demographic information ($N = 41$).

	N	Percent
Nationality		
Canadian	23	56
Other	17	42
Not indicated	1	2
First Language		
English	23	56
Other	18	44
Discipline		
Biochemistry	2	5
Biology	11	27
Chemistry	9	22
Computer science	0	0
Earth science	5	12
Mathematics and statistics	6	15
Physics and physical oceanography	7	17
Psychology	1	2
Previous semesters as a GTA		
0–2	25	61
3–5	12	29
6+	4	10
Preparation		
Undergrad course[a]	6	15
Teaching preparation programme for GS[b]	5	12
Departmental training	5	12
No preparation	21	51
Other	4	10
Teaching in career		
No teaching	4	10
Small to Significant amount	34	83
Career in teaching	3	7

[a]Two GTAs indicated some departmental training; one indicated other training.
[b]One GTA indicated some departmental training; one indicated other training.

undergraduate labs and the role of GTAs – 17 faculty members were identified. In total, the FIS group of respondents consisted of 17 lab staff and 4 faculty members. The administrative offices of each discipline identified a total of 326 GTAs who were emailed invitations to participate. Forty-one GTAs completed the survey. Responses were anonymous except for six GTAs who volunteered their name and contact information for a follow-up interview. The GTA survey was made available for a three-week period during three consecutive semesters from January 2012 to April 2013. Demographic information about GTA participants is provided in Table 2. Six interviews were conducted by two of the authors within six weeks following the survey availability period in the winter 2012 semester. Interviews were semi-structured, conducted in seminar room on campus, audio recorded, and lasted approximately one hour each.

Results

Competency ranking

Of the five competencies ranked most important, three were common to both GTAs and FIS: 6, 'Clearly and effectively communicates ideas and information with students'; 11, 'Uses fair and consistent marking strategies'; and 12, 'Demonstrates concern and respect for all students' (see Table 3). Highest ranked for both groups was competency 6, 'Clearly and effectively communicates ideas and information with students'. This is the only one which appeared in the list of the manuals' five most frequently occurring competencies. Competencies 11 and 12 did not appear in the manuals top five but were ranked seventh and sixth, respectively.

Only the GTAs' top five ranking contained a specific teaching strategy, competency 3, 'Stimulates and facilitates meaningful discussion with students'. Disciplinary knowledge also appeared in the GTAs' rankings. These did not appear in the five highest rankings by the FIS, and were ranked 12th and 17th, respectively, in the manuals.

Further, competency 17 'Adequately plans and prepares for teaching duties' appeared second in the FIS' ranking, but was not in the top five for the GTAs and was ranked 16th in manuals.

GTAs did not rank competency 2, 'Demonstrates a high standard of ethical and professional conduct' in their top five but it was ranked in fifth place by rating of requirement.

Table 3. Top five most important competencies.

Rank	GTAs (sum)	FIS (sum)	Manuals (occurrence)
1	6. Clearly and effectively communicates ideas and information with students (83)	6. Clearly and effectively communicates ideas and information with students (50)	14. Uses a variety of appropriate teaching and learning strategies to help students understand material (180)
2	3. Stimulates and facilitates meaningful discussions with students (56)	17.Adequately plans and prepares for teaching duties (41)	9. Is knowledgeable about institutional, departmental and course policies and procedures, and institutional resources (162)
3	12. Demonstrates concern and respect for all students (47)	11. Uses fair and consistent marking strategies (34)	10. Develops and maintains a positive classroom atmosphere (112)
4	11. Uses fair and consistent marking strategies (46)	12. Demonstrates concern and respect for all students (33)	6. Clearly and effectively communicates information and ideas with students (107)
5	16. Demonstrates a high level of knowledge in the discipline (42)	2. Demonstrates a high standard of ethical and professional conduct (31)	4. Uses self-reflection and feedback from supervisor, peers, and students to improve teaching (102)

While competency 4, 'Uses self-reflection and feedback from supervisor, peers, and students to improve teaching' was among the top five most frequently appearing in manuals, it was a very low priority for GTAs and FIS.

Competency ratings

GTAs and FIS also rated the level of requirement for each of the 20 competencies. There were no significant differences between GTA and FIS mean ratings of requirement (Table 4). Competencies 6, 11, and 12 were the most highly rated for requirement by both groups, which is consistent with the top five ranking. The GTAs' mean rating of competency 16 was ranked in sixth position, which was close to their overall ranking.

The ratings for competency 2, 'Demonstrates a high standard of ethical and professional conduct' were similar for the two groups – means ranked fifth and sixth – and this competency was ranked fifth by FIS in their ranking of the top five.

The rating for competency 3, 'Stimulates and facilitates meaningful discussions with students' was not high for either GTAs or FIS; however, this competency was ranked second by GTAs.

Also appearing in the top five mean ratings by GTAs was competency 20, 'Uses relevant examples to help student understand concepts' but it was not high for FIS and did not appear in the GTAs' top five ranking.

High in the list of the FIS mean ratings of requirement were competencies 17, 'Adequately plans and prepares for teaching duties' and 15, 'Gives frequent, regular, and constructive feedback to students.' Competency 17 was not ranked highly by GTAs but was ranked second by FIS.

Competencies 9, 'Is knowledgeable about institutional, departmental and course policies and procedures and institutional resources', and 19, 'Monitors how well students are progressing with their learning and learning tasks', were rated as the least required competencies and ranked last by both FIS and GTAs. The rating of requirement given to competency 19 was consistent with the manuals. However, FIS and GTAs differ with the manuals' strong emphasis on policies, procedures, and guidelines; it was the second most frequently occurring topic in manuals.

Rating of requirement and self-efficacy

Table 5 presents the GTAs' mean ratings of their self-efficacy along with the mean rating of requirement for each of the 20 competencies. The three competencies for which GTA gave the highest self-efficacy mean rating were: 12, 'Demonstrates concern and respect for all students'; 2, 'Demonstrates a high standard of ethical and professional conduct'; and 18, 'Demonstrates enthusiasm for discipline'. Those with the lowest self-efficacy rating were: 9, 'Is knowledgeable about institutional, departmental and course policies and procedures, and institutional resources'; 4, 'Uses self-reflection and feedback from supervisor, peers, and students to improve teaching'; and 8, 'Demonstrates good presentation skills'. Of particular note among these competencies is competency 12, which was rated the highest for both rating of self-efficacy and level of requirement, and competency 9, which was rated the lowest for both rating of self-efficacy and level of requirement. The mean self-efficacy rating was significantly different from the rating of requirement for nine of the 20 competencies: in all nine, the mean was higher for the rating of requirement.

Table 4. Competency mean rating of requirement and rank of means.

		Competency									
		1. Time management	2. Ethical and professional	3. Discussion	4. Teaching improvement	5. Course expectations	6. Communication	7. Questioning strategies	8. Presentation skills	9. Policies and resources	10. Classroom atmosphere
GTA ($N = 41$)	Mean required rating	4.13	4.30	4.10	3.95	4.05	4.54	4.15	3.68	3.44	4.07
	SD	0.91	0.72	0.97	0.74	1.07	0.81	0.99	1.11	0.84	0.72
	Rank of mean	10	5	11	16	14[a]	2	9	18[a]	20	12[a]
FIS ($N = 21$)	Mean required rating	4.33	4.43	3.90	3.90	3.71	4.57	4.14	4.10	3.00	4.10
	SD	0.48	0.81	0.83	0.70	0.78	0.81	0.85	0.63	0.89	0.77
	Rank of mean	7	6	16[a]	16[a]	18	3	9	11[a]	20	10

		Competency									
		11. Marking	12. Concern and respect	13. Safety	14. Teaching and learning strategies	15. Feedback to students	16. Disciplinary knowledge	17. Preparation	18. Enthusiasm	19. Monitor student learning	20. Examples
GTA ($N = 41$)	Mean required rating	4.32	4.66	4.24	3.93	4.07	4.24	4.05	4.22	3.68	4.32
	SD	1.04	0.53	0.77	0.79	0.75	0.80	0.95	0.73	0.91	0.69
	Rank of mean	3[a]	1	6[a]	17	12[a]	6[a]	14[a]	8	18[a]	3[a]
FIS ($N = 21$)	Mean required rating	4.67	4.67	4.19	4.05	4.45	4.10	4.52	4.00	3.43	4.00
	SD	0.66	0.48	0.81	0.87	0.61	1.00	0.81	0.78	0.93	0.63
	Rank of mean	1[a]	1[a]	8	13	5	11[a]	4	14[a]	19	14[a]

a Indicates a tied position.

Table 5. GTA ratings of self-efficacy and requirement for competencies ($N = 41$).

	Competency									
	1. Time management	2. Ethical and professional	3. Discussion	4. Teaching improvement	5. Course expectations	6. Communication	7. Questioning strategies	8. Presentation skills	9. Policies and resources	10. Classroom atmosphere
Mean self-efficacy rating	3.83	4.24	3.63	3.34	3.58	4.02	3.73	3.50	2.78	4.05
SD	0.92	0.83	0.97	1.04	0.90	0.65	1.10	0.91	1.13	0.84
Rank	11	2[a]	15	19	16	8	12	18	20	7
Mean required rating	4.13	4.30	4.10	3.95	4.05	4.54	4.15	3.68	3.44	4.07
Rank	10	5	11	16	14[a]	2	9	18[a]	20	12[a]
p	.103	.850	.006	.000	.008	.000	.003	.383	.000	.860

	Competency									
	11. Marking	12. Concern and respect	13. Safety	14. Teaching and learning strategies	15. Feedback to students	16. Disciplinary knowledge	17. Preparation	18. Enthusiasm	19. Monitor student learning	20. Examples
Mean self-efficacy rating	4.17	4.46	4.16	3.68	3.71	3.95	3.95	4.24	3.51	4.10
SD	0.83	0.67	1.03	0.79	0.96	0.80	0.89	0.86	0.78	0.70
Rank	4	1	5	14	13	9[a]	9[a]	2[a]	17	6
Mean required rating	4.32	4.66	4.24	3.93	4.07	4.24	4.05	4.22	3.68	4.32
Rank	3[a]	1	6[a]	17	12[a]	6[a]	14[a]	8	18[a]	3[a]
p	.383	.031	.689	.096	.012	.032	.323	.812	.227	.060

[a]Indicates a tied position.

Other characteristics

We compared self-efficacy with the demographic characteristics and found few statistically significant results.

- *Teacher preparation* was significantly related with self-efficacy for only 6 of the 20 competencies: 1, 'Effectively manages personal and work time to fulfil teaching responsibilities' ($p < .01$); 3, 'Stimulates and facilitates meaningful discussions with students' ($p < .01$); 7, 'Effectively uses questioning strategies to promote learning' ($p < .01$); 11, 'Uses fair and consistent marking strategies' ($p < .05$); 16, 'Demonstrates a high level of knowledge in the discipline' ($p < .05$); and 19, 'Monitors how well students are progressing with their learning and learning tasks' ($p < .05$). For all these competencies, the GTAs with 'no teaching preparation' rated themselves lower on self-efficacy.
- *Experience as a GTA* was significantly related to only one self-efficacy rating: 12, 'Demonstrates concern and respect for all students' ($p < .05$). Students with more than two semesters of experience rated themselves less effective in this area than those with fewer than two semesters of experience.
- GTAs whose *first language* is English and those whose first language is not English showed a statistically significant difference in self-efficacy rating for six competencies. GTAs whose first language is not English showed a significantly higher self-efficacy rating for competencies 3, 'Stimulates and facilitates meaningful discussions with students' ($p < .01$); 7, 'Effectively uses questioning strategies to promote learning' ($p < .01$); 11, 'Uses fair and consistent marking strategies' ($p < .05$); and 19, 'Monitors how well students are progressing with their learning and learning tasks' ($p < .05$). Those whose first language is English showed significantly higher ratings of self-efficacy for competencies 1, 'Effectively manages personal and work time to fulfil teaching responsibilities' and 16, 'Demonstrates a high level of knowledge in the discipline'.

Discussion

The results show that, overall, FIS and GTAs agreed on the most and least important competencies required for GTAs to work effectively in undergraduate science labs. Of these competencies, only two were similarly ranked in GTA manuals. We found no strong evidence of a correlation between self-efficacy and teaching preparation or number of semesters of experience as a GTA. Self-efficacy was not related to the GTAs' rating of requirement; however, the competencies which were rated the highest and lowest for self-efficacy were also rated the highest and lowest for requirement.

In the following section, we discuss these results based on four competency groupings: instructional practices, preparedness, engagement with students, and learning environment. The first three of these were used by Cho et al. (2010) in studying GTA roles and responsibilities (these authors used classroom management as the fourth category).

Instructional practices

From our list of 20 competencies, the following related to communication and to teaching and learning strategies were included in the instructional practices category identified by

Cho et al. (2010). They defined instructional strategies as an 'ability to effectively communicate with students and explain contents clearly' (p. 5):

3. Stimulates and facilitates meaningful discussions with students

6. Clearly and effectively communicates information and ideas to students

7. Effectively uses questioning strategies to promote learning

8. Demonstrates good presentation skills

11. Uses fair and consistent marking strategies

14. Uses a variety of appropriate teaching and learning strategies to help students to understand material

20. Uses relevant examples to help students understand concepts

In this category, we also included the following competency not appearing in Cho et al. (2010):

15. Gives frequent and regular and constructive feedback to students

Effective teachers have the ability to explain material plainly, at the student's level of understanding, and in a manner that makes the material stimulating and interesting (Ramsden, 2003). It is, therefore, not surprising that both FIS and GTAs identified competency 6, 'Clearly and effectively communicates information and ideas to students' as the highest ranked competency required by GTAs working in undergraduate science labs. This is consistent with previous research (Deacon & Hajek, 2011; Sohoni et al., 2013) that found the ability to communicate clearly is one of the most important characteristics of GTAs. The higher rating of importance given by GTAs to using discussion, questioning, and the use of examples than to using 'a variety of appropriate teaching and learning strategies' suggests that these competencies should be specifically taught in training programmes for GTAs who will be working in lab environments. While FIS acknowledged the importance of good communication with undergraduate students, they did not specifically identify the ability to stimulate and facilitate discussion as a necessary strength (rated in 16th position). This may be due to a view of labs as being primarily for hands-on, experiential learning. One of the GTAs interviewed indicated that engaging in discussion with students in the lab was an important opportunity to get students 'hooked' on the subject and make connections to the real world. Another interviewee suggested that through discussion the learning experience could be 'broadened' and 'enhanced' beyond that which was demonstrated by the lab coordinator and presented in the lab manual. While GTAs ranked discussion highly (second position), they were not consistent in their response to the role of discussion in their work. Their overall rating of requirement indicates a less significant role for discussion in labs (11th position).

FIS and GTAs had a similar view of the importance of using questioning strategies. Both groups rated it in the ninth position of the 20 competencies. Herrington and Nakhleh (2003) recommend that, rather than solving problems for students or simply providing the 'right answer', GTAs should encourage students to think critically and they must know how to ask questions that guide students to discover the solution. This was recognised by one interviewee who said that he 'guided discovery' by using questions to

challenge students to 'think for themselves'. Another said that, 'To get them to think of what the lab is all about, you have to ask them some questions about the lab itself.' The mean self-efficacy rating ascribed to this competency by GTAs (3.73, 12th in the rank of means) suggests that it is not a strength among the respondents and they might benefit from training in this area.

GTAs participating in this study recognised that they can help students learn by using relevant examples to illustrate concepts. One interviewee spoke about how the use of examples contributed to her own learning as an undergraduate student. She therefore values and uses examples in her teaching: 'I think that's an important role of the TA; to give examples and applications to help fill in that understanding.' FIS did not identify the use of examples as a specific strategy that is important for GTAs to use in the lab for communication of information and ideas (ranked 14th by mean rating of requirement).

Feedback is an essential element for learning and it is common for GTAs in the scientific disciplines to be assigned marking duties for laboratory work. Competency 15, 'Gives frequent, regular and constructive feedback to students' was the only specific teaching and learning strategy that appeared in the FIS top five ranked and rated list of competencies. It is not clear whether FIS expected this skill to be used when marking reports, when encouraging and guiding students in the lab, or both. Like the FIS, GTAs indicated that it is important to be fair and consistent in their marking. However, GTAs gave only a mid-range rating of importance to providing 'frequent, regular, and constructive feedback'. In agreement with the FIS view, we recommend that training programmes help GTAs understand the importance of knowing the laboratory's specific learning outcomes and the level of understanding expected; the benefits of using marking rubrics or guidelines; and the impact of feedback on written and practical work to student learning. One interviewee saw taking the time to provide thoughtful feedback on written work as 'investing in the student'. Engineering GTAs in the 2013 study by Sohoni et al. (2013) indicated that grading student work and providing useful feedback was very important. Doe, Gingerich, and Richards (2013) studied the grading and instructional feedback skills of GTAs working in an introductory psychology course and found that while GTAs gave higher marks than did professional graders both before and after training, subsequent to training, the GTAs did improve in accuracy and consistency, and gave more effective written feedback.

The ability to effectively communicate information through the design and delivery of a presentation is an important skill for both teachers and working scientists. Undergraduate lab classes frequently begin with a demonstration or presentation to introduce students to theory, equipment, and/or experimental methods. Competency 8, 'Demonstrates good presentation skills' was also among the lowest occurring in GTA manuals and among the lowest rated for self-efficacy by the GTAs. None of the interview subjects was required to give presentations. However, it is reasonable to expect that lab and course instructors could call upon GTAs to competently fulfil this role if required.

In a study of the self-efficacy of STEM GTAs, DeChenne and Enochs (2010) found that international GTAs had a significantly higher self-efficacy for instructional strategies than did domestic GTAs. Our results indicated a significantly higher difference in the mean self-efficacy rating for GTAs whose first language is not English for four competencies, three of which appear in our list of instructional practices: 3, 'Stimulates and facilitates

meaningful discussions with students'; 7, 'Effectively uses questioning strategies to promote learning'; and 11, 'Uses fair and consistent marking strategies'.

Preparedness

Previous studies (Cho et al., 2010; Herrington & Nakhleh, 2003; Simpson & Smith, 1993) examined the degree to which GTAs were prepared to fulfil their work responsibilities. These studies asked about content knowledge, departmental policies, and overall preparation. In addition to these, we included competencies related to preparation that appeared frequently in GTA manuals (competencies 1 and 4). Our survey listed the following five competencies related to the GTAs' preparedness for their role:

1. Effectively manages personal and work time to fulfil teaching responsibilities

4. Uses self-reflection and feedback from supervisor, peers, and students to improve teaching

9. Is knowledgeable about institutional, departmental and course policies and procedures and institutional resources

16. Demonstrates a high level of knowledge in the discipline

17. Adequately plans and prepares for teaching duties

Interview subjects identified their major responsibilities to be assisting student with their work in the lab and marking lab reports. Setting up the lab, ensuring a safe environment and conduct in the lab, and teaching students how to use software for data analysis were the other activities mentioned by the interviewees. As employees of the academic department in which they work, GTAs are assigned tasks by faculty members and/or laboratory staff – it is the laboratory staff who are primarily responsible for supervising their work and mentoring them in their role. It is not surprising that competency 17, 'Adequately plans and prepares for teaching duties' was among the top five competencies identified by FIS as important. Related to this competency is the ability to manage time (competency 1). Graduate teaching assistantships are typically allocated a unit of time at an hourly rate of pay. They are expected to manage their time so that they do not exceed the allocated number of work hours. One interviewee indicated that the whole unit of time can be consumed by lab duties and marking responsibilities alone; preparation is therefore unpaid work.

Time management was given a significantly higher rating of requirement by respondents with some teacher preparation and by those beyond their first year of their graduate programme ($p < .05$ and $p < .01$, respectively). This competency was also given a significantly higher rating of self-efficacy by those with some teacher preparation ($p < .05$). This suggests that training and experience may contribute to an appreciation of time management skills and the necessity for preparation time.

GTAs placed a much higher level of requirement on competency 16, 'Demonstrates a high level of knowledge in the discipline' than did FIS. The high level importance that GTAs and undergraduate students place on the GTAs' knowledge of both the laboratory experiment and the underlying theories and concepts was recognised by Herrington and Nakhleh (2003). One interviewee provided the following insight:

> You know everything in the lab but there's [*sic*] some students who will ask you something outside. Do you say you don't know? Is it even allowed to say 'I don't know' or 'Let me find

> out'? … You're faced with this crisis of your abilities as a TA first and then you're also worried that this student might actually think, 'This guy doesn't know anything. So, why would I ask him a question again?'

However, Muzaka (2009) found that academic staff perceived GTAs not to be disadvantaged by a lack of disciplinary knowledge but by a lack of teaching experience. GTA manuals do not devote significant text to how a GTA's level of disciplinary knowledge contributes to the teaching and learning experience. GTA participating in teaching development programmes may benefit from a discussion of what to do and how to react when faced with a question they cannot answer or a problem they cannot solve.

A summary of the responses about teaching preparation is provided in Table 2. Half of the survey respondents had no prior teaching preparation and only a small number had received departmental specific training. One interview subject explained,

> When I started as a TA, I felt like I was just kind of thrown into it. I had no idea what to do on the first day; I was given no guidelines. My first day I was really, like, winging it.

For those who plan to pursue an academic career, a teaching assistantship is often the only opportunity they have to practise teaching and develop teaching skills. It is therefore important for the development of teaching competencies that GTAs receive instruction in teaching and feedback on the quality and effectiveness of their teaching. In GTA manuals, competency 4, 'Uses self-reflection and feedback from supervisor, peers, and students to improve teaching' was the fifth most frequently occurring competency. Lowman and Mathie (1993) found that it was among the four most frequently covered topics and appeared in 83% of 18 manuals surveyed. However, both FIS and GTAs rated the requirement of this competency very low (16th position for both groups) and GTAs also gave a low rating to their self-efficacy in this area (19th position). This indicates that little time and attention is given to providing feedback to GTAs on their teaching and they are not encouraged to take an active role in developing their teaching skills.

All six interview subjects agreed that experience was the best way to develop teaching skills but confirmed that they do not receive feedback on their teaching from laboratory staff or faculty members. The following quotes illustrate the lack of feedback on teaching: 'Some profs will just leave you completely on your own'; 'Everything I learned, I had to learn by myself'. Three interviewees indicated that they did get some feedback on the quality of their marking and all mentioned receiving some informal feedback from students as they interacted with them in the labs. Four commented that formal feedback from both supervisors and students would be welcomed and helpful. The responsibility to be effective in their role and to develop their teaching skills should be promoted in teaching programmes designed for GTAs. By encouraging reflection and teaching specific strategies for getting feedback from students, peers, and supervisors, GTAs will have the information they need to assess and develop their teaching skills.

Shannon et al. (1998) concluded that GTA training programmes spent too much time on university and departmental policies and procedures. Likewise, our research found that this competency was the second most frequently occurring topic in GTA manuals. However, knowledge of institutional, departmental and course policies and procedures and institutional resources was rated as the least important competency by FIS and GTAs. We recommend that training programmes encourage GTAs to know the specific *course* policies and procedures that directly relate to their role and responsibilities as

lab GTAs. Programmes should also encourage GTAs to be proactive and discuss with their supervisors an appropriate response should the GTA encounter undergraduate students with academic or personal issues. One interview subject suggested that while GTAs need not know about specific institutional policies and resources, they should know where to find relevant information if required. For example, interview subjects acknowledged a responsibility regarding academic integrity but admitted that they were unfamiliar with the specific regulations dealing with academic misconduct.

Engagement with students

Of the survey's list of competencies, five related to interpersonal skills and engagement with students:

2. Demonstrates a high standard of ethical and professional conduct

5. Helps students understand course expectations

12. Demonstrates concern and respect for all students

18. Demonstrates enthusiasm for discipline

19. Monitors how well students are progressing with their learning and learning tasks

We note the apparent contradiction between the first-place ranking of competency 12 and the low rating of requirement for competency 19 (ranked in the 18th place by GTAs; 19th place by FIS). We expect that a concern for students' academic performance and personal well-being would be reflected in an effort to monitor their academic progress. Of the six interviews conducted, five participants were asked about the low rating of requirement given to competency 19. All five interpreted it as referring to a responsibility for monitoring overall academic performance in the course or programme as opposed to monitoring learning of a specific laboratory activity and related concepts. Upon further elaboration, two students interpreted this competency to mean keeping students on task so that they could finish the lab activity in the allotted time. Wording that more accurately reflects our intention is 'Monitor how well the students are progressing with the lab activity and their understanding of the related scientific theories and concepts.'

In research conducted by Herrington and Nakhleh (2003), TAs identified the ability to read students' actions and body language and an awareness of typical student difficulties as important in effective laboratory instruction ' … because students aren't normally good at voicing their questions' (p. 1200). It is therefore important for TAs to interact with and monitor students during the laboratory activity. An interview subject recognised this saying, ' … you can see them just kind of staring at it and they don't really know what's going on. They don't feel like asking. It's really important for us to step in at that point.'

Learning environment

Our list of GTA competencies included two related to the learning environment:

10. Develops and maintains a positive classroom atmosphere

13. Maintains a safe and orderly learning space

An optimal learning experience for students is characterised by a positive learning atmosphere. Survey results indicated that FIS and GTAs do not value competency 10 to the same degree as reflected by the frequent occurrence of this competency in GTA manuals. However, GTAs who are friendly and enthusiastic, show concern and respect for all students, provide clear expectations, and are well prepared and organised will contribute to developing a positive atmosphere in the laboratory.

By their nature, lab environments present a greater exposure to potential hazards than do classroom settings. In the ranking of ratings of requirement, GTAs' and FIS ratings for maintaining a safe and orderly working space appeared in sixth and eighth positions, respectively. While survey results indicated that the GTAs' self-efficacy for this competency is high, it cannot be taken for granted and teaching programmes for GTA in the sciences should emphasise the GTAs' responsibility to maintain a safe and orderly learning space. GTAs must know current regulations and guidelines, be able to identify and minimise potential risks or hazards, model safe practice, communicate the importance of safety in the lab, and appropriately respond to any incident. Training programmes should provide general training in lab safety procedures and either provide or advocate for disciplinary-specific training in this area.

Recommendations for training programmes for GTAs in the science disciplines

Laboratory instruction is integral to teaching and learning in the scientific disciplines, and effective teaching in laboratory environments is different from effective teaching in the classroom setting. Though attempts have been made to prepare GTAs for teaching responsibility, GTAs working in undergraduate science laboratories do not find university-wide training programmes effective in helping them to teach in the laboratory setting (Luft et al., 2004). Additionally, manuals are an important resource for helping GTAs with teaching and understanding the value of good teaching, but they are not, by themselves, sufficient to train GTAs for their roles and responsibilities (Lowman & Mathie, 1993). Simpson and Smith (1993) suggest that departments identify, in advance, the specific competencies that TAs should possess and then design training programmes to develop those competencies. In a review of training programmes, Shannon et al. (1998) recommended much greater emphasis on pedagogical methods, and Park (2004) recommended the inclusion of both generic and subject-specific elements.

At the institution where this study was undertaken, approximately 170 graduate students are employed as GTAs in undergraduate science labs each semester. Neither the institution nor the individual academic units maintain records with demographic information about the GTAs such as that listed in Table 2. A limitation of this study is the small sample size (13%) and our inability to judge whether survey respondents were representative of the general population of GTAs in the sciences. Also, we could not examine discipline-specific training needs. As mentioned, we acknowledge the lack of clarity for the wording of competency 19, and wonder how wording that more accurately reflected our intention (Monitor how well the students are progressing with the lab activity and their understanding of the related scientific theories and concepts) would have affected overall ranking and rating of the competencies.

From the mean scores, we note the GTAs' apparent lack of discrimination in assessing the level of importance and self-efficacy for each competency. Like earlier studies (Shannon et al., 1998; Sohoni et al., 2013) that found GTAs rated their competence in teaching significantly higher than faculty and undergraduate student rated them, this suggests that the GTAs have a high level of confidence (perhaps over confidence) in their ability to teach effectively. Self-efficacy should therefore not be a significant factor when determining training requirements for GTAs.

The heavy reliance on GTAs in laboratory instruction has prompted us to examine the teaching competencies required for GTAs to work effectively in undergraduate student laboratories. With knowledge of the specific skills required, we can make recommendations about training programmes and resources for these GTAs. The results allow us to make the following suggestions for teaching development programmes for GTAs in the scientific disciplines:

- focus on the development of questioning strategies as a means of promoting critical thinking and learning;
- encourage GTAs to prepare and use examples to help illustrate concepts and demonstrate relevance;
- encourage the use of marking rubrics or guidelines and discussion of grading standards and criteria with academic staff and peers to ensure fair and consistent marking of student work;
- emphasise the importance of reflection and feedback and encourage GTAs to seek out and use feedback to enhance their teaching skills;
- stress time management strategies and the value of appropriate preparation for teaching duties which includes both instructional strategies and knowledge of the lab activity and underlying concepts;
- encourage GTAs to know relevant *course* policies and procedures, be familiar with where to find information about departmental and institutional policies, procedures and resources, and to consult with supervisors about responding to academic and personal issues

We have identified important knowledge and skills that should be considered in the design of a GTA training programme in a faculty of science based on a review of GTA manuals and the opinions of GTAs, and faculty and lab coordinators. Other researchers may use the survey designed for this study (with the suggested edit to competency 19) to examine disciplinary differences and provide information to enhance the design of discipline-specific training opportunities for GTAs. This study has not considered the scholarship of teaching and learning in STEM in the post-secondary setting; there is research to be done comparing the teaching competencies in this literature and that of GTA development.

Disclosure statement

No potential conflict of interest was reported by the authors.

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