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Learning from errors: students' and instructors' practices, attitudes, and beliefs

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ABSTRACT

In some educational contexts, such as during assessments, it is essential to avoid errors. In other contexts, however, generating an error can foster valuable learning opportunities. For instance, generating errors can improve memory for correct answers. In two surveys conducted at three large public universities in North America, we investigated undergraduate students' and instructors' awareness of the pedagogical benefits of generating errors, as well as related practices, attitudes, and beliefs. Surveyed topics included the incorporation of errors into learning activities, opinions about the consequences of studying errors, and approaches to feedback. Many students had an aversion towards making errors during learning and did not use opportunities to engage in errorful generation, yet studied or analysed errors when they occurred. Many instructors had a welcoming attitude towards errors that occur during learning, yet varied in providing students with resources that facilitate errorful generation. Overall, these findings reveal the prevalence of an ambivalent approach to errors: Students and instructors avoid generating errors but prioritise learning from them when they occur. These results have important implications for the implementation of pretesting, productive failure, and other error-focused learning techniques in educational contexts.

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Making errors and mistakes in assessments and other high-stakes situations often results in unwanted consequences, and accordingly most human beings have an aversion towards doing so. However, a frequently overlooked benefit of errors is that they can lead to valuable learning opportunities. In the mid-to-late twentieth century, Skinner (1953), Bandura (1986), and others (e.g., Ausubel et al., 1968), believing that generating errors increases the likelihood of their recurrence (a premise that was, ironically, erroneous), advocated for *errorless learning*—that is, entirely eliminating or minimising errors from education and training situations. In contrast, recent laboratory and classroom research shows that *errorful learning*—that is, generating errors and subsequently receiving correct answer feedback—can lead to better memory for correct information than errorless learning (e.g., Bjork et al., 2015; Kornell et al., 2009). Whether learners and educators appreciate this updated perspective on the pedagogical benefits of errors remains unclear. The present manuscript examines the degree to which undergraduate students and university instructors embrace learning from errors, as well as related practices and beliefs.

Generating errors benefits learning

Errors can be defined as facts or processes that do not match given norms (Oser & Spychiger, 2005; for a taxonomy, see Reason, 1995), and a growing body of research indicates that generating them (and then processing correct answer feedback) can yield substantial learning benefits (for a review, see Metcalfe, 2017). For example, generating and/or studying errors can help learners acquire *negative knowledge* (Gartmeier et al., 2008; Minsky, 1997), which is an understanding of incorrect facts and processes and how they differ from correct counterparts. That knowledge can be useful in determining correct information or actions in the future. In some cases, generating an error can enhance learning relative to not generating one at all. This rather counterintuitive finding is supported by studies of *pretesting* and *productive failure*, which are described in turn next.

Studies of pretesting typically have two conditions: pretesting and reading. In the pretesting condition, learners take pretests on information that they have yet to learn, a process that commonly involves generating numerous errors (e.g., generating "*Sydney*" in response to "*The capital city of Australia is _____*"). After pretesting, the correct answers (e.g., "*Canberra*") are shown. In the reading condition, participants simply study correct information from the outset (e.g., "*The capital city of Australia is Canberra*") and do not answer any questions or generate any errors. On a subsequent criterial test, the typical finding is that pretesting yields better memory for the correct answers than reading. This *pretesting effect* or *errorful*

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generation effect has been replicated with a wide range of educationally-relevant stimuli, including video-recorded lectures (e.g., Carpenter & Toftness, 2017), scientific texts (e.g., Richland et al., 2009), foreign language vocabulary (e.g., Potts & Shanks, 2014), and facts (e.g., Kornell et al., 2009), and has also been demonstrated in classrooms (e.g., Bjork et al., 2015), across different retention intervals (e.g., Little & Bjork, 2015), and when the correct answer is shown immediately or up to 24 hrs later (Kornell, 2014). Although more research on pretesting is needed to fully establish its pedagogical potential (including to address the degree to which guesses need to be somewhat informed (e.g., Kang et al., 2011), the role of associative strength between pretested cues and targets (e.g., Grimaldi & Karpicke, 2012; Knight et al., 2012; cf. Metcalfe & Huelser, 2020), as well as the finding that high confidence errors followed by feedback yields more learning (Butterfield & Metcalfe, 2001), which is also known as *hypercorrection*), and not all studies have shown benefits of pretesting (e.g., Geller et al., 2017), this body of research suggests that students often stand to benefit from taking pretests or attempting practice questions before new course content is presented (Pan et al., 2020). Such pretesting could occur before relevant readings, lectures, or discussion sections are completed, during which the correct answers could be learned.

In studies of *productive failure,* learners attempt to produce solutions to novel problems before receiving instruction on the correct solution (e.g., Holmes et al., 2014; Kapur, 2008; Kapur & Rummel, 2012; for a review, see Kapur, 2015). In these studies, initially attempting and failing to solve an unfamiliar problem (e.g., a problem that requires the application of principles from Newtonian physics), which frequently involves generating erroneous solutions, often enhances learning from subsequent instruction and practice relative to being instructed from the outset. Thus, attempting and failing to solve a problem can be helpful for learning. Benefits of productive failure have been demonstrated in such domains as physics (e.g., Kapur, 2008), statistics (e.g., Loibl & Rummel, 2014), and engineering (e.g., Lai et al., 2017), and also in classrooms and across extended retention intervals (e.g., Trueman, 2014). Although more research into productive failure is also needed to fully establish its pedagogical potential, the findings to date suggest that if students are given the opportunity to solve new problem types before the correct solutions are presented, then they may be able to learn those solutions more effectively.

As indicated by the growing literature showing benefits of pretesting and productive failure, researchers are increasingly affirming the pedagogical value of generating errors in educational contexts. More broadly, the finding that generating errors enhances learning aligns with the observation that learning techniques that are more error-prone or challenging, at least initially, can be ultimately more effective than comparatively error-free and easier techniques, although more effortful processing may not always facilitate learning (e.g., Geller et al., 2020; Pan, Tajran, et al., 2019; Taylor et al., 2020). Bjork (1994) described such learning techniques (e.g., retrieval practice and distributing out learning over time) as "desirable difficulties" (see also Pan & Bjork, in press; Schmidt & Bjork, 1992). It remains to be investigated, however, whether learners are open towards more error-prone learning techniques or instead regard errors as a sign of an ineffective learning technique.

Prior research on practices and beliefs involving learning from errors

Several popular learning strategy surveys, including the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1991) and the Learning and Study Strategies Inventory (LASSI; Weinstein & Palmer, 2002), include individual items that address learning from errors (e.g., in the MSLQ, learners rate their level of agreement with the statement: "*Even when I do poorly on a test I try to learn from my mistakes*"). However, these surveys do not specifically concentrate on learning from errors. Of the studies that have done so, most target K-12 instructors' teaching practices and attitudes (for a review, see Matteucci et al., 2015). Such studies have often used observational methods (i.e., video recordings) and have commonly addressed cross-cultural differences (e.g., Dalehefte et al., 2012; Santagata, 2005; Stigler et al., 1999) or whether instructors promote a positive *error climate* wherein errors are accepted and well-integrated into the social environment (e.g., Steuer et al., 2013; Tulis, 2013). These studies provide compelling evidence of cultural variation in discussions of errors, the frequency of such discussions, and attitudes towards errors. For instance, among middle school math instructors, American teachers tend to minimise or deemphasise students' errors, Italian teachers tend to be overtly critical of errors, and Japanese and Chinese teachers often have a positive attitude towards errors and devote substantial amounts of time to discussing them with their students (Santagata, 2005; Stevenson & Stigler, 1994; Stigler et al., 1999).

A few studies have examined relationships between students' or instructors' approaches to errors and academic outcomes (e.g., Steuer et al., 2013). These studies provide some evidence that positive error climates are associated with academic achievement (e.g., Steuer & Dresel, 2015). For example, Leighton et al. (2018) found that undergraduate students' academic achievement goals were predictive of their willingness to publicly disclose and discuss the errors that they had made in their classes.

Recent empirical research suggests that most learners lack an appreciation for the pedagogical benefits of generating errors. Huelser and Metcalfe (2012) had undergraduate students learn a series of weakly-associated word pairs (e.g., *bagel - breakfast*) via pretesting (e.g., attempting to generate the answer to *bagel -?*, after which the correct answer, *breakfast*, was shown as

feedback) or reading (i.e., viewing intact word pairs for an equivalent period of time), take a recall test, and then rank the relative efficacy of the methods that they had used. In both experiments, there was strong evidence of a pretesting effect, yet most students ranked pretesting as less effective than reading. The authors proffered two potential explanations for this metacognitive illusion. First, students may have considered the occurrence of errors during pretesting as evidence of a poor learning technique (Bjork, 1994). Alternatively, students may have had a preexisting bias against believing that generating errors is helpful for learning.

Similarly, Yang et al. (2017) found that adult participants did not appreciate the benefits of pretesting for learning word pairs. That pattern was observed when participants judged the efficacy of pretesting versus reading for learning individual word pairs (i.e., judgments were solicited at the item level) and when they made global judgments (i.e., across all pretested and all read pairs). Directly informing participants of the pretesting effect, however, did make them more appreciative of the benefits of errorful generation, resulting in item-level judgments of learning that were higher for pretested than read word pairs. Yang et al. also conducted a brief online survey wherein participants were asked to imagine using reading and pretesting to learn word pairs and predict the relative efficacy of the two methods; reading was judged to be more effective by a 65-to-35% margin. Building on Huelser and Metcalfe's (2012) explanations, Yang et al. suggested that preexisting beliefs about the pedagogical utility of generating errors and reading may be a source of these inaccurate assessments. Overall, both studies reveal a disconnect between the amount of learning that results from generating errors and learners' beliefs in the pedagogical benefits of doing so.

The present study

The foregoing work by Huelser and Metcalfe (2012) and Yang et al. (2017) suggests that many learners are unaware of and do not appreciate the benefits of learning from errors, at least in the context of the pretesting effect. If so, then many students might not prioritise error generation, studying errors, and/or learning from feedback on errors in their course preparation and associated activities. Indeed, some instructors report such patterns in their courses (e.g., Mason & Singh, 2010), but their prevalence has yet to be widely investigated. Further, observational research by Stigler et al. (1999), Santagata (2005), and others highlights the existence of multiple instructional approaches to errors in K-12 classes, including differences in the frequency and manner of relevant discussions. The relative popularity of these approaches at the university level, however, remains unexplored. Finally, any exploration of learning from errors occurs against the backdrop of the historically influential errorless learning approach. In discussions that informed the development of this research, some instructors speculated that errorless learning remains fairly prevalent.

To address these issues, we employed a survey approach akin to that used by Geller et al. (2018), Kornell and Bjork (2007), McCabe (2011), Wissman et al. (2012) and others wherein we directly questioned respondents about their practices, attitudes, and beliefs. We fielded two surveys, one for undergraduate students and another for instructors (similar to Morehead et al., 2016). Our primary goal was to measure beliefs and attitudes about learning from errors at the undergraduate level, including any aversion towards errors or bias against the belief that generating errors improves learning. We also investigated related topics, including reactions to errors when they occur, beliefs about the frequency and sources of errors, experiences and attitudes towards feedback, and the extent to which students and instructors incorporate errorful learning into their own learning activities.

Method

Participants

Both the student and instructor surveys were administered at three large public research universities in Canada and the United States (McMaster University in Hamilton, Ontario; University of California, Los Angeles (UCLA) in Los Angeles, California; and University of California, San Diego (UCSD) in La Jolla, California) between March and June 2020. The surveys were approved by each university's Institutional Review Board (IRB) and administered online. Participation in each survey was completely voluntary. Demographic information for the respondents is listed in Tables 1 and 2. Combined across sites, the sample sizes for the student and instructor surveys were 1,052 and 141 respondents, respectively.

Student survey

At McMaster University, the student survey was administered as an extra credit opportunity for students in an introductory psychology class, PSYCH 1X03 ("Introduction to Psychology, Neuroscience, & Behaviour"), which is a large-enrollment lower-division course that attracts students from a variety of different majors. At UCLA, the student survey was administered as an extra credit opportunity in two lower-division courses that are prerequisites for natural science majors: Physics 1B ("Physics for Scientists and Engineers: Oscillations, Waves, Electric and Magnetic Fields") and Physics 5C ("Physics for Life Sciences Majors: Electricity, Magnetism, and Modern Physics"). At UCSD, the student survey was offered as a participation credit opportunity (worth up to 1% of the course grade) in an upper-division physiology course, BIPN 134 ("Human Reproduction"). The UCLA and UCSD courses, which cover foundational materials in their subject areas, are large-enrollment courses that attract

Table 1. Student survey respondent demographics.

Demographic category	Characteristics	Combined sample	McMaster	UCLA (1B)	UCLA (5C)	UCSD
Sample size						
	Total (*n*)	1,052	191	161	337	363
	Response rate	96%	n/a	85%	97%	100%
Gender						
	Female	70%	79%	77%	n/a	42%
	Male	30%	20%	23%	n/a	57%
	Other	0%	0%	0%	n/a	<1%
	Decline to state	<1%	1%	0%	n/a	1%
Age						
	Mean, in yrs	20.0	18.7	18.8	n/a	21.1
Ethnic background						
	Aboriginal	<1%	1%	0%	n/a	0%
	African American or Black	2%	2%	1%	n/a	2%
	Asian or Pacific Islander	45%	39%	52%	n/a	45%
	Caucasian or White	29%	46%	31%	n/a	20%
	Latinx	11%	1%	6%	n/a	19%
	Other	12%	12%	9%	n/a	13%
	Decline to state	1%	1%	2%	n/a	1%
Academic major						
	Business or finance	<1%	3%	0%	0%	0%
	Clinical sciences	5%	21%	0%	0%	3%
	Engineering	8%	4%	46%	0%	0%
	Humanities or liberal arts	1%	3%	<1%	1%	<1%
	Mathematics or computing	5%	4%	28%	<1%	0%
	Natural sciences	67%	35%	20%	78%	95%
	Social sciences	11%	23%	1%	20%	2%
	Undeclared or decline to state	3%	8%	5%	1%	0%

Note: 1B = Physics 1B, 5C = Physics 5C, and n/a = data not collected or not applicable.

undergraduate students from a wide range of majors and are regularly taught by the third and fourth authors, respectively.

The number of respondents per sample was between 161 and 363 (total $n = 1{,}052$ respondents). As illustrated in Table 1, the combined sample across all sites was

Table 2. Instructor survey respondent demographics.

Demographic category	Characteristics	Combined sample	McMaster	UCLA	UCSD
Sample size					
	Total (*n*)	141	40	59	42
Years of teaching experience					
	0–5 yrs	23%	5%	31%	31%
	6–10 yrs	20%	25%	14%	24%
	11–15 yrs	16%	15%	10%	24%
	16–20 yrs	11%	18%	5%	12%
	Over 21 yrs	30%	38%	41%	10%
Level primarily taught					
	Undergraduate	74%	68%	71%	83%
	Undergraduate and graduate equally	14%	23%	19%	0%
	Graduate	11%	10%	8%	17%
	Post-graduate	1%	0%	2%	0%
Current position					
	Professor	27%	25%	44%	5%
	Associate professor	11%	33%	2%	2%
	Assistant professor	16%	23%	15%	10%
	Teaching professor or lecturer	23%	8%	14%	52%
	Adjunct professor	4%	3%	7%	2%
	Emeritus professor	1%	3%	2%	0%
	Postdoctoral scholar	1%	3%	0%	2%
	Graduate teaching assistant	16%	5%	15%	26%
	Academic advisor or administrator	1%	0%	2%	0%
Subject area					
	Business or finance	2%	3%	2%	2%
	Clinical sciences	2%	8%	0%	0%
	Engineering	13%	13%	3%	29%
	Humanities or liberal arts	7%	15%	0%	10%
	Mathematics or computing	10%	5%	17%	5%
	Natural sciences	48%	13%	75%	43%
	Social sciences	15%	35%	3%	12%
	Decline to state	3%	10%	0%	0%

fairly diverse in terms of ethnic background and academic major.

Instructor survey

At all three institutions, the instructor survey was advertised via university-wide faculty email listservs (sent with the assistance of a local campus teaching centre), as well as via departmental email listservs and directories. The number of respondents per sample was between 40 and 59 instructors (total $n = 141$ respondents). As illustrated in Table 2, respondents included instructors with a considerable range of teaching experience, with most focused on undergraduate teaching and the most common area of expertise in the natural sciences. Variation between samples can be attributed in part to the composition of the mailing lists and the willingness of different departments to assist with publicising the survey.

Materials

Both surveys were designed to address three main categories of interest: (1) learning and teaching practices regarding errors and mistakes; (2) practices involving the presentation and use of feedback on errors and mistakes; and (3) attitudes, beliefs, reactions, and other opinions regarding errors, mistakes, and feedback. The survey questions originated from a list of 54 items that the first author drafted in consultation with the second author. Drawing on their teaching expertise in their respective subject areas, the other authors then helped select, refine, and/or add to those items, resulting in 31 and 16 questions appearing on the student and instructor surveys, respectively (the latter kept relatively short per teaching centre requests). Many of the same or similar questions appeared on both surveys.

The survey questions were multiple-choice and largely identical across the different survey sites. We sought to present questions in a neutral context, including in the wording and selection of answer options (cf. Tversky & Kahneman, 1981). Questions addressing learning practices primarily featured four answer options addressing frequency (*often, sometimes, not very often*, and *never*), whereas questions on attitudes and beliefs primarily featured four-option scales of importance or helpfulness (e.g., *very helpful, moderately helpful, minimally helpful,* and *not at all helpful*) or five-option scales of positivity or agreement (including a neutral option). In cases where respondents could choose between a list of possible actions or responses, a fill-in-the-blank "Other" option was provided. Per IRB request, the McMaster University instructor survey allowed respondents to decline answering any question; such instances were rare and are not discussed further. Additionally, at the end of the student survey, participants were asked to provide responses to the 9-item Multidimensional Perfectionism Scale (Frost et al., 1990) and the 7-item Attitudinal Cognition Subscale (Leighton et al., 2018); both scales were added as exploratory measures and the results are accessible via the Open Science Framework at: https://osf.io/uycre/.

In line with recommendations by Krosnick and Presser (2010) and others, questions on both surveys were grouped by topic and were largely ordered from general to specific. Further, questions involving learning practices generally preceded questions involving opinions and beliefs. A series of demographic questions appeared before or after the survey questions. To ensure that respondents understood the questions being asked (Kalton & Schuman, 1982), we defined "errors and mistakes" at the outset of both surveys using concrete examples (*"calculating an answer incorrectly, recalling incorrect information, misunderstanding a concept or idea, among other possibilities"*). Other jargon terms (e.g., "error rate") were also defined or replaced using plain language. The surveys were further reviewed for comprehensibility by undergraduate students and instructors prior to their administration.

Student survey

The student survey consisted of: (a) 7 questions about self-regulated learning activities, (b) 7 questions involving how instructors approach errors or feedback, (c) 4 questions involving hypothetical learning scenarios, and (d) 13 questions involving attitudes and beliefs. The questions on (a) addressed how often errors are made during learning; time spent studying, correcting, or analysing errors and/or feedback; methods of learning from errors; and time engaged in specific activities that involve error generation or pretesting. The questions on (b) drew on prior research into instructors' approaches to errors in the classroom (e.g., Santagata, 2005; Stevenson & Stigler, 1994) and addressed the frequency of discussions involving errors and mistakes, the manner in which errors and mistakes are discussed, and students' perceptions of instructors' attitudes and reactions. The four scenarios addressed in (c) included pretesting (e.g., Kornell et al., 2009), techniques that yield more or less errors (e.g., Schmidt & Bjork, 1992), changes in error rates (e.g., Bjork, 1994), and productive failure (e.g., Kapur, 2008). Questions on (d) addressed attributions for errors; beliefs about generating, correcting, and studying errors; the importance and optimal timing of feedback; and degree of endorsement in each of six statements about the role of errors for learning (cf. Leighton et al., 2018).

The student survey usually took respondents 15–20 min to complete. One exception involved Physics 5C students at UCLA, for which the student survey was the final part of a larger questionnaire that addressed experiences specific to the course itself (e.g., whether students had studied for that course on their own or with a partner, how much of the assigned readings they had completed, and what prior relevant courses they had taken); that entire questionnaire took up to 30 min to complete.

Instructor survey

The instructor survey consisted of: (a) 7 questions about teaching activities and (b) 9 questions focused on attitudes and beliefs. All but two questions corresponded to those on the student survey. The exceptions were a question on discussing the value of learning from errors and another question on the amount of errors that successful students tend to make. Further, at the end of the survey, an optional open-ended question gave instructors the opportunity to elaborate on their responses to any of the earlier questions and provide additional comments. The instructor survey usually took respondents 5–10 min to complete.

Procedure

Both surveys were accessed online. The instructions directed respondents to answer each question as honestly as possible. Students were further told to answer on the basis of their entire undergraduate experience and instructors were told to answer on the basis of their entire teaching experience (that instruction may have been especially pertinent given that classroom instruction at all three institutions shifted online during the survey period due to the global coronavirus pandemic). Students were also assured that their credit was not contingent on any of their answers and all respondents were told that their answers would not be disclosed in any publicly identifiable way. Each survey was completed within a 1-hour time window. The surveys automatically ended once respondents had finished responding to all the questions.

Results and discussion

Descriptive statistics for the student and instructor surveys are presented in Tables 3–8, respectively. For simplicity, questions have been organised into the tables by type (e.g., practices, beliefs). Across the samples from McMaster University, UCLA, and UCSD, the general response patterns to most questions were similar for the student survey and for the instructor survey. Accordingly, in our interpretation and reporting of the data, we focused on results for combined datasets—that is, results for the student survey that were combined from all sampled sites, as well as data for the instructor survey that were combined in the same manner. These results can be found in each table under the column labelled "Combined sample." All datasets are archived at the Open Science Framework and accessible at: https://osf.io/uycre/.

Our presentation of the results begins with our findings for students (from the student survey) followed by our findings for instructors (drawing on both instructor and student survey data, as there were relevant questions in both surveys). For brevity, the order in which the survey questions are discussed does not exactly match the order in the tables.

Students' learning practices

How errors during learning are addressed

As detailed in Table 3, the vast majority (83%) of students report sometimes or often making errors during their own learning. Efforts to learn from those errors are common: 90% report sometimes or often spending time studying or analysing their errors. To do so, students most often use the following techniques: (a) determining the correct method and contrasting it with what led to the error (75%), (b) studying the error itself (73%), and (c) studying feedback on the error (72%). Additionally, 60% report often going back to correct their errors on their own, and in a follow-up question addressing the frequency of engaging in the study of feedback when it is provided, 92% indicate sometimes or often doing so. Thus, students commonly make errors during learning, and when they do, report often making attempts to correct or study the errors and/or feedback.

Use of opportunities for errorful learning

Despite often making efforts to learn from errors when they occur, most students do not engage in errorful generation as a means of enhancing learning. If and when practice questions are provided, just 14% often attempt them before completing relevant readings, lectures, or discussion sections. Afterwards, 69% often attempt them; at this point, the correct responses are likely to be known, and although learning from errors could still occur during such practice (e.g., when retrieval failures occur), the full benefits of pretesting likely cannot be realised. A similar pattern is evident for the case of practice questions found in textbooks: Most students (52%) report never attempting such questions before doing the relevant reading, but many report sometimes or often attempting them during (59%) or after (74%) the reading has already been performed. These patterns indicate that many students do not often use practice questions to engage in errorful generation and pretesting, possibly because of an unawareness of the pedagogical benefits of doing so.

Students' attitudes and beliefs

Beliefs regarding errors during learning

As detailed in Table 4, the vast majority of students express an aversion towards committing errors during learning. Ninety-one percent believe that it is moderately important or very important to avoid such errors. Just 2% believe that avoiding them is not at all important. Fewer students, however, endorse going to extreme measures to avoid errors—that is, avoiding them "as much as possible" (43% somewhat or strongly agree). Further, most students believe that errors should be considered as somewhat positive or very positive (79%) from the standpoint of "being a successful learner," that making errors is a normal part of the learning process (78% strongly agree), that studying errors is moderately helpful or very helpful

Table 3. Students' self-regulated learning activities involving errors and feedback.

No.	Questions	Choices	Combined sample	McMaster	UCLA (1B)	UCLA (5C)	UCSD
1.	When studying or practising for the academic subjects that you are trying to master, how often do you make errors or mistakes (such as calculating an answer incorrectly, misunderstanding a concept or idea, among other possibilities)?	Often	50%	41%	54%	52%	51%
		Sometimes	43%	48%	42%	42%	42%
		Not very often	7%	11%	4%	6%	7%
		Never	0%	0%	1%	0%	1%
2.	In your own learning, how often do you spend time studying or analysing the errors that you make?	Often	46%	38%	45%	48%	48%
		Sometimes	44%	52%	43%	41%	42%
		Not very often	10%	10%	9%	11%	9%
		Never	1%	1%	2%	0%	1%
3.	If you study or analyse the errors or mistakes that you make, which of the following methods do you use (you may choose more than one)?	I study my errors or mistakes	73%	72%	76%	70%	75%
		I study feedback on my errors or mistakes	72%	72%	71%	70%	82%
		I determine the correct method and contrast it with what I did that led to my error	75%	71%	81%	61%	72%
		I try to connect my errors or mistakes with prior mistakes to find patterns	27%	25%	25%	76%	27%
		I try to correct my errors or mistakes on my own	53%	54%	70%	29%	58%
		I go back and study the topics/skills that I made an error or mistake in	72%	69%	75%	41%	77%
		I seek out instructors or tutors for help	32%	23%	37%	67%	38%
		I seek out peers for help	58%	69%	62%	29%	57%
		I try similar exercises or assignments	65%	65%	70%	52%	66%
		I do not specifically try to learn from my errors or mistakes	1%	1%	1%	62%	1%
4.	In your own learning, how often do you go back and correct the errors or mistakes that you have made?	Often	60%	59%	58%	62%	58%
		Sometimes	33%	34%	34%	31%	35%
		Not very often	6%	6%	6%	7%	7%
		Never	1%	1%	2%	0%	1%
5.	If you receive feedback on the errors or mistakes that you make (that is, are told or find out specifically how many and which errors you have made), how often do you spend time studying or analysing that feedback?	Often	51%	40%	55%	52%	53%
		Sometimes	41%	49%	37%	39%	40%
		Not very often	7%	10%	7%	6%	7%
		Never	1%	1%	1%	1%	0%
		I do not receive feedback	0%	0%	0%	1%	0%
6.	In your undergraduate courses, if and when practice questions are provided:						
	a. How often do you attempt to solve them *before* doing the *relevant* assigned reading or attending the relevant lecture/discussion section?	Often	14%	16%	12%	12%	17%
		Sometimes	28%	35%	37%	16%	31%
		Not very often	40%	34%	40%	47%	36%
		Never	18%	15%	11%	25%	15%
	b. How often do you attempt to solve them *after* doing the relevant assigned reading or attending the *relevant* lecture/discussion section?	Often	69%	54%	68%	80%	67%
		Sometimes	24%	32%	25%	17%	28%
		Not very often	5%	11%	6%	3%	4%
		Never	1%	3%	1%	0%	1%
7.	Many textbook chapters have practice questions associated with them, either interspersed throughout the chapter or at the end of the chapter. Regarding those questions:						
	a. How often do you attempt to answer those questions *before* doing the assigned reading?	Often	2%	2%	3%	1%	1%
		Sometimes	11%	14%	18%	4%	13%
		Not very often	35%	39%	48%	20%	41%
		Never	52%	45%	30%	74%	45%
	b. How often do you attempt to answer those questions *as you are* doing the assigned reading?	Often	20%	16%	22%	21%	22%
		Sometimes	39%	42%	42%	31%	43%
		Not very often	23%	25%	24%	21%	24%
		Never	17%	16%	12%	27%	11%
	c. How often do you attempt to answer those questions *after* doing the assigned reading?	Often	34%	40%	40%	28%	33%
		Sometimes	40%	36%	42%	39%	41%
		Not very often	17%	17%	14%	18%	18%
		Never	10%	6%	4%	15%	8%

Note: 1B = Physics 1B and 5C = Physics 5C.

(96%), and that one learns more from errors than correct responses (76% somewhat agree or strongly agree). Eighty percent of students somewhat or strongly disagree with the possibility that making errors during learning increases the likelihood of the same errors being committed again in the future—contrary to the views of learning theorists that championed the errorless learning approach. Thus, although the belief in avoiding errors during learning is widespread among students, that belief is often accompanied by an awareness of the pedagogical value of such errors and, in particular, the benefits of studying them.

Students also commonly endorse the value of error correction: 87% consider it very important to go back and correct errors. Further, if feedback on errors is provided, 56% believe that such feedback would be the most beneficial for learning if it is provided immediately. That practice has received mixed support in the feedback literature, however (e.g., Kornell, 2014; Metcalfe et al., 2009; Mullet et al., 2014; for review see Bangert-Drowns et al., 1991), with one account suggesting that students pay closer attention to immediate feedback due to higher levels of interest (Kulik & Kulik, 1988).

Scenarios involving errorful learning

As detailed in Table 5, when presented with a hypothetical scenario wherein pretesting or studying could be used to memorise information, students' opinions on the relative effectiveness of both methods are somewhat split: 56% believe that pretesting would be more effective and 44% believe the reverse. This pattern provides further evidence that awareness of the benefits of errorful generation is not widespread among undergraduate students, which is broadly consistent with results reported by Huelser and Metcalfe (2012) and Yang et al. (2017) but without as strong of a bias against the technique.

When asked to estimate the relative efficacy of learning techniques that yield some errors versus few or no errors at all, opinions are also split: 53% believe that the former is more effective whereas 47% believe the reverse. These patterns suggest that awareness of "desirable difficulties" (Bjork, 1994; wherein better learning techniques are often more error-prone) is not particularly strong among students. Further, when learning something for the first time, most students prefer a gradual drop (54%) or rapid drop (39%) in error rate. That finding is consistent with a desire to reduce errors during learning.

Finally, in a scenario involving learning to solve a challenging physics problem, students are somewhat split in their preference for methods that involve some form of instructional support (i.e., scaffolding), productive failure, or neither: 29% prefer being instructed on how to solve the challenging problem from the outset, 45% prefer practising with simpler problems and transitioning gradually towards the more challenging version, and 27% prefer attempting the challenging problem on one's own before any instruction is provided. Notably, the latter option is the most error-prone and, in some instances, possibly the most beneficial (e.g., Kapur, 2008).

Attributions and reactions to errors during learning

Students commonly attribute errors during learning to a lack of practice (38%), carelessness (22%), or misconceptions with target materials (19%). Emotional reactions vary, with the most common including frustration (30%), disappointment (16%), and motivation to try harder (12%). Most students also somewhat agree or strongly agree (65%) that making mistakes makes them feel less intelligent, whereas opinions are split regarding whether errors would be reduced if an instructor is "doing a good job" (29% each agree and disagree). These results suggest that negative reactions to errors are common, but not ubiquitous.

Instructors' learning practices

How errors during learning are addressed

As detailed in Table 7, there is substantial evidence that instructors discuss errors in their courses. Seventy-five percent of instructors report that they sometimes or often discuss errors during lectures or discussion sections; 95% sometimes or often do so during office hours; and 45% and 66% sometimes or often do so via announcements on course websites and via online messaging systems, respectively. When discussing errors, instructors state that they most frequently focus on the misconceptions that lead to those errors (94%). How to correct errors is the next most commonly used approach (76%). In addition, 74% of instructors report that they sometimes or often discuss the benefits of learning from errors with their students.

The timing of instructor-provided feedback on errors and mistakes varies substantially. Such feedback most often occurs later in the same week (33%) or one week after (40%) an exam or assignment. The three most common feedback methods are: (a) marking specific answers as correct or incorrect (84%), (b) giving an overall score such as percent correct (82%), and (c) providing correct answers to individual questions (75%). From the perspective of the feedback literature, however, it is notable that (a) and (b) are potentially ineffective whereas (c) is more likely to facilitate learning (e.g., Pashler et al., 2005; see also Bangert-Drowns et al., 1991). Additionally, as detailed in Table 6, student survey data indicate that 62% of instructors sometimes or often provide at least some feedback on errors and mistakes, but a substantial portion, 38%, do not often do so.

Providing opportunities for errorful learning

Instructors could potentially facilitate or encourage students to engage in errorful learning by furnishing relevant resources. As indicated in Table 7, 50% of instructors sometimes or often provide practice questions before relevant readings, lectures, or discussion sections are completed, whereas 75% do so after relevant course content has

Table 4. Students' attitudes and beliefs towards errors and feedback.

No.	Questions	Choices	Combined sample	McMaster	UCLA (1B)	UCLA (5C)	UCSD
1.	In your own learning, what is the most common reason for the errors or mistakes that you make?	Carelessness	22%	25%	27%	26%	14%
		Fatigue	8%	12%	4%	10%	5%
		Misconceptions about the materials	19%	15%	12%	22%	20%
		Inherent difficulty of the materials	9%	4%	16%	9%	9%
		Lack of practice with the materials	38%	41%	35%	30%	46%
		Information communicated ineffectively to me	3%	3%	4%	1%	4%
		Other	2%	1%	1%	2%	2%
2.	When you are learning something and make an error or mistake, what is your most common emotional reaction?	Anger	2%	4%	2%	3%	1%
		Anxiety	11%	6%	11%	12%	15%
		Curiosity	10%	6%	8%	14%	10%
		Disappointment	16%	15%	14%	17%	17%
		Disgust	0%	0%	1%	1%	0%
		Embarrassment	3%	4%	1%	1%	4%
		Enthusiasm	0%	0%	0%	0%	0%
		Frustration	30%	38%	40%	24%	27%
		Happiness	0%	1%	0%	0%	0%
		Irritation	9%	7%	8%	12%	6%
		Motivation (to try harder)	12%	14%	9%	12%	13%
		Sadness	2%	2%	2%	1%	3%
		Surprise	1%	2%	2%	1%	1%
		Other	2%	2%	3%	0%	3%
3.	During the learning of an academic subject (e.g., biology, chemistry, or physics), how important is it for you to avoid making errors or mistakes?	Very important	35%	39%	31%	32%	38%
		Moderately important	46%	47%	52%	46%	42%
		Minimally important	17%	12%	16%	21%	18%
		Not at all important	2%	2%	2%	1%	2%
4.	From the standpoint of being a successful learner, how *positive* ("it's a good thing") or *negative* ("it's a bad thing") do you believe the making of errors or mistakes should be regarded?	Very positive	28%	25%	21%	32%	29%
		Somewhat positive	51%	55%	52%	45%	54%
		Neither positive nor negative	12%	13%	16%	14%	9%
		Somewhat negative	8%	7%	11%	9%	7%
		Very negative	1%	1%	1%	1%	1%
5.	When learning an academic subject, how helpful do you believe it is to spend time studying the errors or mistakes that you have made?	Very helpful	69%	66%	64%	66%	77%
		Moderately helpful	27%	29%	32%	30%	21%
		Minimally helpful	3%	4%	2%	4%	2%
		Not at all helpful	0%	0%	1%	0%	0%
6.	When learning an academic subject, how important do you believe it is to correct the errors or mistakes that you have made (that is, to go back and modify your responses)?	Very important	87%	83%	82%	88%	91%
		Moderately important	12%	14%	17%	11%	9%
		Minimally important	1%	3%	1%	1%	0%
		Not at all important	0%	1%	1%	0%	0%
7.	When do you believe is the best time for feedback to be given on the errors or mistakes that one has made?	Immediately	56%	61%	52%	49%	61%
		Later in the same day	24%	21%	27%	25%	24%
		Later in the same week	18%	15%	20%	23%	14%
		A week later	2%	3%	0%	3%	1%
		Two or more weeks later	0%	0%	0%	0%	0%
8.	Rate this statement: "During learning, one should work to *avoid* making errors or mistakes as much as possible."	Strongly agree	10%	8%	17%	13%	7%
		Somewhat agree	33%	30%	41%	31%	32%
		Neither agree nor disagree	19%	22%	18%	19%	19%
		Somewhat disagree	30%	29%	20%	31%	32%
		Strongly disagree	8%	10%	4%	5%	10%
9.	Rate this statement: "Making errors or mistakes is a normal part of the learning process."	Strongly agree	78%	86%	81%	71%	80%
		Somewhat agree	19%	11%	18%	25%	17%
		Neither agree nor disagree	2%	2%	0%	2%	2%
		Somewhat disagree	0%	0%	1%	1%	0%
		Strongly disagree	1%	1%	0%	1%	1%
10.	Rate this statement: "We learn more from an error or mistake than we do from a correct response or success."	Strongly agree	30%	31%	24%	28%	35%
		Somewhat agree	46%	46%	43%	46%	48%
		Neither agree nor disagree	14%	16%	19%	16%	9%
		Somewhat disagree	7%	5%	12%	8%	6%
		Strongly disagree	2%	2%	2%	2%	2%
11.	Rate this statement: "When an instructor is doing a good job, students tend to not make errors or mistakes."	Strongly agree	8%	7%	9%	8%	8%
		Somewhat agree	29%	31%	33%	30%	25%
		Neither agree nor disagree	28%	34%	20%	26%	30%
		Somewhat disagree	29%	24%	29%	29%	31%
		Strongly disagree	7%	5%	9%	7%	6%

(*Continued*)

Table 4. Continued.

No.	Questions	Choices	Combined sample	McMaster	UCLA (1B)	UCLA (5C)	UCSD
12.	Rate this statement: "Making errors or mistakes during learning *increases* the likelihood that one will make the same errors at a later point."	Strongly agree	2%	3%	2%	2%	2%
		Somewhat agree	9%	7%	12%	11%	8%
		Neither agree nor disagree	8%	11%	8%	6%	9%
		Somewhat disagree	47%	51%	44%	44%	48%
		Strongly disagree	33%	28%	34%	37%	32%
13.	Rate this statement: "When I make a mistake it makes me feel less intelligent."	Strongly agree	17%	17%	16%	18%	17%
		Somewhat agree	48%	51%	49%	45%	48%
		Neither agree nor disagree	18%	19%	15%	19%	18%
		Somewhat disagree	12%	9%	17%	12%	12%
		Strongly disagree	5%	3%	4%	5%	5%

Note: 1B = Physics 1B and 5C = Physics 5C.

been covered. Thus, instructors provide practice questions more commonly for practising recall of materials that have already been learned (at least partially), rather than specifically for errorful generation. However, practice assignments, assignments that are graded for completion only, and other activities wherein performance does not impact the course grade are sometimes or often (74%) provided. These resources could be used for errorful learning, but are not necessarily designed specifically for that purpose.

Instructors' attitudes and beliefs

Beliefs regarding errors during learning

As detailed in Table 8, many instructors strongly agree (79%) that errors are a normal part of the learning process, that it is very helpful (67%) for students to spend time studying the errors that they make on exams or assignments, and that one learns more from errors than correct responses (62% somewhat agree or strongly agree). Further, very few instructors strongly agree that it is important to avoid errors during learning "as much as possible" (9%), that students make fewer errors when an instructor "is doing a good job" (1%), or that successful students make fewer mistakes during learning (5%). In addition, most instructors do not endorse the belief that making errors during learning increases the likelihood of the same errors being committed again in the future (77% somewhat disagree or strongly disagree), which mirrors patterns observed in the student data and further suggests that errorless learning has fallen out of favour. Overall, these results indicate that most instructors are open to students making errors during learning, believe that such errors are not necessarily a sign of poor instruction, and do not regard such errors as detrimental for future performance.

With respect to how feedback on students' errors and mistakes should be timed to help learning, many

Table 5. Students' views of learning scenarios involving errors and feedback.

No.	Questions	Choices	Combined sample	McMaster	UCLA (1B)	UCLA (5C)	UCSD
1.	If your goal is to memorise the answers to a set of questions on an academic subject (e.g., biology, chemistry, or physics), which method would be more effective?	First trying to *guess* the answers (and possibly making many *incorrect guesses*), then studying the correct answers	56%	51%	54%	63%	53%
		Studying the correct answers from the outset	44%	49%	46%	37%	47%
2.	When used for studying or practising, some learning techniques result in more errors and mistakes than others. Which is more effective for learning?	Learning techniques that yield *some errors* during studying and practising	53%	53%	49%	60%	49%
		Learning techniques that yield *few or no errors* during studying and practising	47%	47%	51%	40%	51%
3.	When you are learning for the first time, sometimes errors or mistakes are unavoidable. Which of the following *error rates* (i.e., the fraction of problems that I make an error on) is better for your learning?	Error rate rapidly drops	39%	28%	43%	43%	43%
		Error rate gradually drops	54%	63%	52%	50%	50%
		Error rate gradually rises	3%	3%	2%	3%	3%
		Error rate quickly rises	0%	0%	0%	0%	0%
		Error rate remains stable	4%	6%	2%	4%	4%
4.	When you are learning a difficult skill, such as how to solve a challenging physics problem, which of the following learning methods would you prefer?	From the outset, having the instructor walk you through how to solve the problem correctly	29%	32%	24%	31%	27%
		First practising with simpler versions of a problem and then working gradually up to the challenging version	45%	39%	47%	45%	47%
		First trying to solve challenging problems on your own, and then having the instructor show you how to do so	27%	29%	29%	24%	26%

Note: 1B = Physics 1B and 5C = Physics 5C.

Table 6. Students' instructional experiences involving errors and feedback.

No.	Questions	Choices	Combined sample	McMaster	UCLA (1B)	UCLA (5C)	UCSD
1.	In your courses, how often do your instructors (i.e., professors, TAs) spend time discussing the errors or mistakes that students make:						
	a. During lectures?	Often	4%	3%	1%	5%	4%
		Sometimes	33%	37%	23%	38%	31%
		Not very often	54%	51%	61%	47%	58%
		Never	10%	9%	15%	10%	7%
	b. During discussion sections?	Often	14%	6%	6%	19%	16%
		Sometimes	50%	47%	50%	52%	51%
		Not very often	31%	41%	36%	25%	29%
		Never	5%	6%	8%	4%	4%
	c. During office hours?	Often	34%	40%	29%	36%	31%
		Sometimes	45%	39%	55%	45%	44%
		Not very often	16%	15%	14%	13%	21%
		Never	5%	7%	2%	6%	4%
2.	If and when your instructors discuss errors or mistakes that students make, which of the following do they commonly *focus* on?	How to correct those errors	23%	33%	23%	18%	22%
		How to avoid those errors	15%	17%	17%	13%	14%
		The misconceptions that lead to those errors	60%	48%	55%	67%	61%
		Other	1%	1%	1%	0%	1%
		My instructors do not discuss errors or mistakes	3%	2%	4%	2%	3%
3.	Which of the following best describes the typical *approach* that your instructors take towards errors or mistakes?	At the moment when a student makes an error or mistake, they will *discuss* it	18%	16%	24%	19%	15%
		At the moment when a student makes an error or mistake, they will tend to *ignore* it	2%	2%	2%	2%	1%
		They will specifically bring up potential errors or mistakes that students *may* make	30%	30%	39%	33%	23%
		They will specifically bring up errors or mistakes that students *have* made	49%	51%	34%	46%	58%
		Other	1%	1%	2%	0%	3%
4.	In your courses, how often do you receive feedback from your instructors on the errors or mistakes that you have made?	Often	19%	21%	17%	21%	18%
		Sometimes	43%	43%	44%	44%	42%
		Not very often	35%	32%	34%	33%	38%
		Never	3%	3%	5%	2%	2%
5.	When does that feedback, if any, usually occur?	Immediately	14%	22%	10%	12%	13%
		Later in the same day	13%	16%	14%	12%	11%
		Later in the same week	26%	19%	36%	24%	28%
		A week later	25%	20%	20%	27%	27%
		Two or more weeks later	13%	12%	9%	17%	12%
		I usually do not receive feedback	9%	11%	11%	8%	9%
6.	In general, how *positive* ("it's a good thing") or *negative* ("it's a bad thing") would you describe your instructors' attitudes towards the errors or mistakes that students make during the learning of new materials, skills or topics?	Very positive	20%	24%	14%	22%	17%
		Somewhat positive	38%	34%	41%	35%	42%
		Neither positive nor negative	32%	33%	34%	32%	30%
		Somewhat negative	10%	9%	9%	9%	11%
		Very negative	1%	1%	1%	1%	1%
7.	What would you describe is your instructors' most common *emotional reaction* towards the errors or mistakes that students make?	Anger	0%	0%	0%	0%	1%
		Curiosity	33%	31%	34%	34%	33%
		Disappointment	14%	17%	8%	11%	17%
		Enthusiasm	21%	21%	25%	26%	13%
		Frustration	5%	8%	3%	4%	5%
		Happiness	2%	2%	0%	3%	2%
		Irritation	5%	4%	4%	4%	8%
		Sadness	1%	3%	1%	1%	1%
		Surprise	8%	6%	6%	6%	13%
		Other	11%	8%	19%	0%	8%

Note: 1B = Physics 1B and 5C = Physics 5C.

instructors believe that feedback on assignments should occur either immediately (37%) or later in the same week (36%), whereas feedback on exams is most commonly thought to be beneficial when it occurs later in the same week (45%). As previously noted, research on the optimal timing of feedback is mixed.

Attitudes and reactions to errors during learning

Instructors commonly regard errors that occur during learning as somewhat positive or very positive (75%), with far fewer expressing a somewhat negative or very negative evaluation (4%). These results are largely substantiated by the student survey data, with students reporting

that their instructors commonly have somewhat positive or very positive attitudes to errors that occur during learning (58%), with the most common emotional reactions including curiosity (33%) and enthusiasm (21%), but also disappointment (14%). Overall, these results are consistent with the finding that many instructors have a generally welcoming approach to errors that occur during learning.

Instructors' open-ended comments

Twenty-seven instructors answered the optional open-ended question at the end of the instructor survey. The most common comments reflected individual beliefs about learning from errors (e.g., "*Making mistakes is never the goal, but when it happens, at least make use of it*"; "*Obviously you should try to avoid mistakes. But when mistakes happen, they can be really helpful to study*"). Several respondents commented on logistics (e.g., the resources that would be required to provide immediate feedback). Other comments focused on individual teaching practices (e.g., varying feedback methods depending on assignment type) and limitations of the survey questions (e.g., pointing out cases wherein there is not one correct answer).

General discussion

We investigated undergraduate students' and instructors' practices, attitudes, and beliefs in regard to learning from errors. Across both surveys, a host of intriguing findings emerged, two of which are especially salient. First, students and instructors often avoid opportunities for errorful generation. That is, most students do not use pretests and half of surveyed instructors do not provide practice questions in advance of relevant course content. These findings contrast with the greater adoption of other evidence-based learning techniques such as retrieval practice (Kornell & Bjork, 2007) and distributed practice (e.g., Morehead et al., 2016), although the pedagogical benefits of those techniques are often not fully recognised by their users either (e.g., Hartwig & Dunlosky, 2012). Second, both students and instructors acknowledge the value of errors when they are committed. Students often attempt to correct their errors and make efforts to learn from them in several ways (e.g., comparing erroneous and correct methods, analysing errors, and studying feedback), whereas instructors commonly discuss students' errors in lectures, discussion sections, office hours, and other venues. When errors do occur, they are usually not ignored.

Interestingly, both students and instructors believe that committing an error does not irrevocably increase the likelihood of its recurrence, which is a critical but flawed assumption on the part of prominent twentieth century learning theorists (e.g., Bandura, 1986; Skinner, 1953) that informed the errorless learning approach. That result suggests that errorless learning is not as influential as it once was, at least at the undergraduate level. Further, it appears that the avoidance of errorful generation is unrelated to a fear of remembering misinformation. Rather, errors may simply make the learning process disfluent (for related discussion see Bjork et al., 2013). Students' associations of errors with undesirable outcomes, including negative emotional states and reduced appraisals of their own intelligence, may also contribute to their avoidance of errorful generation (and may contribute to a preference for techniques that do not involve making errors, as shown in the Huelser & Metcalfe, 2012; and Yang et al., 2017 studies).

Together, the present findings reveal the prevalence of an arguably ambivalent or conditional approach to learning from errors among undergraduate students and instructors. Under this approach, the deliberate generation of errors is rare. However, if and when errors do occur, efforts are made to learn from them. As discussed next, there are compelling reasons to expect that this approach is popular.

Accounting for students' and instructors' approaches to learning from errors

The student survey results appear to stem from the fact that instructors commonly evaluate learning via course grades (McMorran et al., 2017). Accordingly, most students' primary objective is to learn course content to a level that will allow them to obtain a desired grade. To achieve that objective, errors must be avoided, and especially on high-stakes exams and graded assignments. Consequently, students quickly develop an aversion to errors. Crucially, our data indicate that this aversion to errors is pervasive—that is, it extends beyond situations wherein errors are costliest and encompasses the learning process itself.

By this account, students consider errors that occur during learning, which they often attribute to insufficient or poor preparation and have negative emotional reactions towards, as indicators of suboptimal performance. Accordingly, errors are undesirable. However, learning from errors when they occur is valued insofar as such learning may help prevent the recurrence of errors in the future. Thus, the study or analysis of errors and feedback on errors, as well as error correction, is prioritised because those practices serve as preventative measures. Importantly, that prioritisation can manifest without any awareness of the capacity of errorful generation to enhance learning and memory (i.e., that deliberately making errors can have pedagogical benefits). All that is required is an understanding that errors can serve as a reference for actions or responses to avoid in the future (Gartmeier et al., 2008).

A similar account can be applied to the instructor survey results. Instructors aim to impart accurate knowledge and commonly make efforts to help their students perform well in their courses. Accordingly, instructors treat errors that occur during learning as welcome developments (i.e., they often foster a positive error climate) insofar as those errors provide opportunities for error correction, enable students to acquire negative knowledge, help

Table 7. Instructors' teaching activities involving errors and feedback.

No.	Questions	Choices	Combined sample	McMaster	UCLA	UCSD
1.	On average, how *often* do you spend instructional time discussing, with your students, the errors and mistakes that they make:					
	a. During lectures or discussion sections?	Often	25%	23%	15%	40%
		Sometimes	50%	53%	53%	43%
		Not very often	25%	25%	31%	17%
		Never	1%	0%	2%	0%
	b. During office hours?	Often	70%	55%	76%	74%
		Sometimes	25%	40%	17%	21%
		Not very often	4%	3%	5%	2%
		Never	2%	3%	2%	2%
	c. Via online postings on a course website?	Often	12%	13%	3%	24%
		Sometimes	33%	38%	27%	38%
		Not very often	31%	23%	46%	19%
		Never	23%	28%	24%	19%
	d. Via online messaging such as email, chat, or a discussion forum?	Often	23%	15%	22%	33%
		Sometimes	43%	45%	41%	43%
		Not very often	25%	33%	27%	14%
		Never	9%	5%	10%	10%
2.	If and when you discuss with students the errors or mistakes that they make, which of the following do you do (please select all that apply)?	How to correct those errors	76%	78%	70%	84%
		How to avoid those errors	63%	56%	58%	72%
		The misconceptions that lead to those errors	94%	98%	90%	93%
		Other	7%	7%	5%	9%
		I do not discuss errors or mistakes	0%	0%	0%	0%
3.	In your teaching, how often do you provide practice questions that students can attempt:					
	a. *Before* relevant assigned readings or lectures?	Often	27%	30%	22%	31%
		Sometimes	23%	30%	15%	29%
		Not very often	28%	25%	32%	24%
		Never	22%	15%	31%	17%
	b. *After* relevant assigned readings or lectures?	Often	46%	40%	51%	45%
		Sometimes	29%	35%	24%	31%
		Not very often	16%	18%	15%	14%
		Never	9%	8%	10%	10%
4.	Besides assignments and exams wherein student performance counts towards course grades, how often do you provide students with the opportunity to make errors (or study them) without their performance impacting their course grade? Examples include practice assignments, assignments that are graded for completion only, and others.	Often	41%	38%	42%	43%
		Sometimes	33%	30%	31%	38%
		Not very often	20%	23%	20%	17%
		Never	6%	10%	7%	2%
5.	On exams and assignments, feedback (that is, how many errors were made, which errors were made, and/or what the correct answers were) can be given. Regarding feedback and its placement after an exam or an assignment:					
	a. Do you provide feedback for *assignments*, and if so, when?	Immediately	13%	10%	12%	19%
		Later in the same day	3%	0%	0%	10%
		Later in the same week	33%	28%	34%	36%
		A week later	40%	38%	46%	36%
		Two or more weeks later	8%	20%	5%	0%
		No feedback at all	2%	3%	3%	0%
	b. Do you provide feedback for *exams*, and if so, when?	Immediately	4%	8%	0%	7%
		Later in the same day	6%	0%	5%	14%
		Later in the same week	34%	25%	36%	40%
		A week later	40%	30%	54%	31%
		Two or more weeks later	6%	13%	5%	2%
		No feedback at all	6%	18%	0%	5%
6.	If and when you provide feedback, what forms do you commonly provide (please select all that apply)?	Providing an overall score, such as percent correct	82%	80%	76%	88%
		Marking specific answers as correct or incorrect	84%	76%	83%	88%
		Providing correct answers to specific questions, (e.g., via an answer key)	75%	54%	82%	84%
		Providing explanations of correct or incorrect answers	75%	80%	72%	70%
		Other	9%	2%	8%	16%
7.	In your teaching, how often, if at all, do you discuss the potential value of learning from one's errors and mistakes?	Often	31%	33%	24%	40%
		Sometimes	43%	40%	42%	45%
		Not very often	21%	25%	25%	12%
		Never	5%	3%	8%	2%

Table 8. Instructors' attitudes and beliefs towards errors and feedback.

No.	Questions	Choices	Combined sample	McMaster	UCLA	UCSD
1.	From the standpoint of being a successful learner, how *positive* ("it's a good thing") or *negative* ("it's a bad thing") do you believe that students' making of errors or mistakes (as they are learning new materials or skills) should be regarded?	Very positive	32%	23%	36%	36%
		Somewhat positive	43%	43%	36%	52%
		Neither positive nor negative	22%	35%	22%	10%
		Somewhat negative	3%	0%	7%	0%
		Very negative	1%	0%	0%	2%
2.	How helpful do you believe it is for your students to spend time studying the errors or mistakes that they make on exams and/or assignments?	Very helpful	67%	45%	76%	76%
		Moderately helpful	28%	48%	22%	19%
		Minimally helpful	2%	3%	2%	2%
		Not at all helpful	2%	5%	0%	2%
3.	Regarding feedback on students' errors and mistakes and their placement after an exam or an assignment:					
	a. From the standpoint of helping students' learning, when is the best time to provide feedback for *assignments*?	Immediately	37%	38%	39%	33%
		Later in the same day	16%	18%	14%	17%
		Later in the same week	36%	20%	41%	45%
		A week later	11%	25%	7%	5%
		Two or more weeks later	0%	0%	0%	0%
		No feedback at all	0%	0%	0%	0%
	b. From the standpoint of helping students' learning, when is the best time to provide feedback for *exams*?	Immediately	23%	28%	20%	21%
		Later in the same day	16%	18%	14%	17%
		Later in the same week	45%	23%	58%	50%
		A week later	11%	15%	8%	10%
		Two or more weeks later	0%	0%	0%	0%
		No feedback at all	2%	5%	0%	2%
4.	Rate this statement: "Making errors or mistakes is a normal part of the learning process."	Strongly agree	79%	73%	75%	90%
		Somewhat agree	16%	23%	19%	5%
		Neither agree nor disagree	1%	0%	2%	0%
		Somewhat disagree	0%	0%	0%	0%
		Strongly disagree	5%	5%	5%	5%
5.	Rate this statement: "We learn more from an error or mistake than we do from a correct response or success."	Strongly agree	29%	20%	29%	38%
		Somewhat agree	33%	35%	31%	36%
		Neither agree nor disagree	28%	28%	32%	24%
		Somewhat disagree	6%	13%	7%	0%
		Strongly disagree	2%	3%	2%	2%
6.	Rate this statement: "Making errors or mistakes during learning *increases* the likelihood that one will make the same errors at a later point."	Strongly agree	4%	5%	0%	7%
		Somewhat agree	9%	8%	14%	5%
		Neither agree nor disagree	10%	8%	12%	10%
		Somewhat disagree	37%	43%	36%	33%
		Strongly disagree	40%	38%	39%	45%
7.	Rate this statement: "During learning, one should work to *avoid* making errors or mistakes as much as possible."	Strongly agree	9%	10%	10%	7%
		Somewhat agree	22%	13%	31%	19%
		Neither agree nor disagree	20%	23%	22%	14%
		Somewhat disagree	26%	35%	17%	29%
		Strongly disagree	23%	20%	20%	31%
8.	Rate this statement: "When an instructor is doing a good job, students tend to not make errors or mistakes."	Strongly agree	1%	0%	0%	2%
		Somewhat agree	11%	15%	12%	7%
		Neither agree nor disagree	25%	33%	25%	17%
		Somewhat disagree	37%	38%	37%	36%
		Strongly disagree	26%	15%	25%	38%
9.	Rate this statement: "Successful students make fewer mistakes during learning than others."	Strongly agree	5%	3%	7%	5%
		Somewhat agree	24%	20%	34%	14%
		Neither agree nor disagree	23%	30%	25%	14%
		Somewhat disagree	31%	30%	27%	38%
		Strongly disagree	16%	18%	7%	29%

identify content that students are struggling with in the course, and serve as opportunities to obtain feedback on their own teaching. As with students, this approach can manifest without any awareness of the benefits of errorful generation for learning and memory.

More broadly, students' and instructors' typical approach to learning from errors is analogous to that which is commonly observed for retrieval practice. Students and instructors often use practice tests and value them for their assessment purposes, but overlook their ability to enhance learning (Hartwig & Dunlosky, 2012; Kornell & Bjork, 2007). Many learning scientists, however, argue that the capacity of retrieval practice to enhance learning and memory is the technique's most important benefit (e.g., Dunlosky et al., 2013; Pan & Rickard, 2018).

The benefits of errorful generation are unappreciated

The present results reveal that many students have little awareness of the fact that making errors, followed by correct answer feedback, improves memory (e.g., Kornell et al., 2009; Pan & Bjork, in press). When predicting the relative effectiveness of learning techniques in a hypothetical scenario, students only modestly favoured errorful learning over the study of correct answers. Similarly, many students did not express a preference for learning techniques that are more error-prone, which is a hallmark of "desirable difficulties" (Bjork, 1994), or prefer learning to solve problems via techniques that would be likely to induce productive failure (Kapur, 2015). However, it does not appear that many students have a strong bias against believing that generating errors is helpful for learning; rather, their baseline beliefs appear to be relatively agnostic on the issue. Accordingly, when making experience-based metacognitive judgments in experimental paradigms (e.g., Huelser & Metcalfe, 2012; Yang et al., 2017), learners possibly rely on other cues to inform their judgments (which may lead to being swayed by feelings of fluency and other characteristics), with those cues commonly leading to a stated preference for reading and studying over errorful generation. However, when errors do occur, they are commonly treated as learning opportunities.

Our findings for instructor- or textbook-provided practice questions provide further evidence that the benefits of errorful generation are unappreciated. Most students never or rarely use such questions to engage in pretesting, yet commonly use them to engage in retrieval practice (for related findings, see Hartwig & Dunlosky, 2012; Kornell & Bjork, 2007; Pan & Sana, 2020). Further, instructors provide relevant resources (e.g., practice questions in advance of relevant course content) on an inconsistent basis. That pattern can be interpreted as another indication that the benefits of errorful generation are unappreciated, and it may also contribute to students' infrequent use of pretesting.

Preferred versus actual learning practices

In several instances, students' and instructors' practices fell short of stated preferences. For instance, the rate at which students engage in error correction (60%) is substantially less than their endorsement of its importance (87%). That result suggests a disparity between intended and actual learning behaviours (see Blasiman et al., 2017 for analogous findings involving distributed practice). Additionally, 92% of students report spending time studying or analysing feedback when it is provided, which implies a strong positive evaluation of such feedback, yet 38% of their instructors reportedly seldom or never provide it (higher rates of feedback were however reported in the instructor survey). Further, 80% of students prefer immediate or same-day feedback, yet such feedback is reportedly provided only 27% of the time (analogous patterns were observed in the instructor survey data). All of these patterns may reflect logistical and other challenges that impede the implementation of desired learning practices.

Limitations and future research

Limitations of the present study could be addressed in future research. Although the survey results are likely generalisable to students and instructors at other universities, particularly in North America, additional studies involving non-Western cultures are advisable to address potential cultural differences (cf. Santagata, 2005; Stigler et al., 1999). Random samples could be used to reduce any effects of selection bias. Potential moderating influences of academic achievement level (e.g., Geller et al., 2017) and academic mindset (e.g., Rattan et al., 2015) could also be investigated. Notably, our data relied entirely on self-report measures that asked respondents to make judgments on issues and topics that were, in some cases, fairly abstract; independent verification of learning behaviours where feasible (e.g., Blasiman et al., 2017) could be used to test the accuracy and validity of those measures. In addition, future surveys could field a greater variety of questions to further probe students' and instructors' approaches to learning from errors. Such questions might include more fine-grained answer options to explore different methods of analysing errors, various types of feedback, and more diverse learning contexts. The types of errors that are made (which could range from somewhat plausible to completely off the mark) could also be explored.

Relatedly, further research on the efficacy of pretesting and productive failure is needed before either technique can be endorsed for widespread use. Such research might occur in authentic educational environments (e.g., Geller et al., 2017), and for the case of pretesting, address the specificity of learning that has repeatedly been observed in some experiments (e.g., James & Storm, 2019; cf. Pan, Lovelett, et al., 2019), the role of surprise (Butterfield & Metcalfe, 2001), the finding that generating errors that are semantically related to the correct answers

yields more potent learning (Cyr & Anderson, 2018; Zawadzka & Hanczakowski, 2019), various types of pretest and criterial test questions (e.g., St. Hilaire et al., 2019), and the absence of pretesting effects for materials that lack strong cue-target associations (e.g., Grimaldi & Karpicke, 2012; cf. Seabrooke et al., 2019). These studies could help clarify potential benefits and limitations of generating errors for learning.

Practical implications

In terms of application, our most important finding is that many undergraduate students and instructors currently undervalue and underutilise errorful generation. Although research on the benefits of pretesting and productive failure is still ongoing, compelling evidence already exists regarding the efficacy of such techniques across a variety of pedagogical circumstances (and for pretesting especially). Accordingly, when choosing how information should be processed and how study time should be allocated (Dunlosky & Ariel, 2011; Nelson & Narens, 1990), students and instructors should be cognisant of the benefits that errorful generation can provide. Even a brief discussion of the benefits of making errors can be impactful (e.g., Yang et al., 2017). Moreover, facilitating errorful generation need not be highly complex; for instance, instructors could simply provide practice questions—which are already often implemented—earlier or after a minimal amount of prerequisite instruction has occurred. We submit that it is not enough to simply value learning from errors; the deliberate generation of errors, followed by feedback, should be considered as a viable learning technique. A growing awareness of the benefits of errorful learning among instructors and students has the potential to augment learning with minimal costs: Pretests can be used to introduce and practice materials and productive failure can be embraced to help consolidate learning.

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