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Enhancing engineering students' confidence using interactive teaching methods - Part 2: post-test results for the Force Concept Inventory showing enhanced confidence

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ABSTRACT: It is the fundamental responsibility of educators when educating students to ensure that students acquire essential capabilities and skills so that they can tackle difficult problems that need to be solved, and be able face a multitude of challenges in their professional and personal lives. Students should also be able to evaluate realistically their own knowledge. This creates demands for educators to develop teaching methods and arrangements that support students' understanding of difficult abstract concepts, and to guide students towards self-efficacy and good self-confidence. The aim of this research was to investigate students' initial knowledge of basic mechanics when entering their engineering studies and their confidence levels regarding test answers being correct. In this study, the authors also sought to study what learning and confidence outcomes can be achieved by applying student-centred teaching methods. The differences in confidence between male and female students were also studied. The Force Concept Inventory (FCI) was utilised and was complemented with a grid for confidence evaluation. This study revealed that interactive teaching methods had an impact on students' confidence evaluations.

CONFIDENCE AND SELF-EFFICACY

Education involves many activities that are governed by tangible goals and outcomes to be achieved in this process. One of the important goals is to guide students to acquire the ability to evaluate their knowledge. This includes being able to realistically assess their work. In engineering education, it is important that students have good problem-solving skills and the abilities to evaluate reliably the results that they have achieved when working on problems and design issues, as well as the ability to see the results in a wider context.

Engineering students, both female and male, differ in their background studies and learning styles, and thus have different abilities when studying science and engineering subjects, so that a deeper understanding is achieved. This creates a challenge for educators to develop teaching methods and arrangements that support student understanding of difficult abstract concepts and guide them to self-efficacy and good self-confidence.

There are many reasons for freshmen of engineering and science subjects dropping out. Some students find engineering and science subjects uninteresting and difficult. Some lack the belief that they will succeed in their studies and career as engineers. According to many studies, freshmen female students do not believe much in their abilities to succeed in engineering subjects as their male freshmen counterparts do. Female students have been reported to lack faith in their capabilities in subjects in science, technology, engineering and mathematics (STEM) [1-3]. Although women have succeeded in their studies, they can be less confident than men. Rayman and Brett found that women have lower self-confidence, perceived ability and self-reliance than men, even though their grade point averages are equal to or higher than men's [4]. The difference in confidence can be so clear that men who have not succeeded in graduating in their engineering programmes are nevertheless more confident of their abilities to succeed in engineering compared to women who have graduated [5][6]. A study conducted during a freshman year shows that female students have experienced a decrease in the level of confidence in their ability to engage in science compared with a matched sample of high achieving male students [3]. This was partly attributed to men being less affected by poor teaching, poor organisation of course materials and dull course content. Adelman's report on women's and men's engineering paths mentions that women who leave their studies do not do so because of poor academic performance [7]. More often, female students experience a higher degree of academic dissatisfaction [7][8].

Branden defines self-efficacy as confidence in the functioning of one's mind, ability to think, understand, learn, choose and make decisions [9]. It also relates to confidence in one's ability to understand the facts of reality that fall within the sphere of one's interests and needs. Self-efficacy includes concepts such as self-trust and self-reliance. Self-efficacy is deeper than confidence in one's specific knowledge and skills and is based on past successes and accomplishments. However, one's knowledge and skills nurture self-efficacy.

According to Bandura, people's beliefs about their efficacy can be developed by four main sources of influence, namely:

- Through mastery experiences: successes build a robust belief in one's personal efficacy, while failures undermine it.
- Through vicarious experiences provided by social models: seeing people similar to oneself succeed by sustained effort raises observers' beliefs that they, too, possess the capabilities to master comparable activities to succeed.
- Social persuasion strengthens people's beliefs that they have what it takes to succeed: people who are persuaded verbally that they possess the capabilities to master given

activities are likely to mobilise greater effort and sustain it than if they harbour self-doubts and dwell on personal deficiencies when problems arise.
- Through structuring situations that bring success and avoid placing people in situations prematurely where they are often likely to fail. Success should be measured in terms of self-improvement rather that by triumphs over others [10][11].

Chou used an instruction-based approach and a behaviour-modelling training method to study the effects of training methods on learners' computer self-efficacy and learning performance [12][13]. Their studies showed that the training method made a difference with respect to gender and learning outcomes, and that subjects with various learning styles performed substantially different in some learning tasks. It could also be seen that the chosen training method had an impact on self-efficacy, being also gender sensitive.

The teaching methods and arrangements selected have an important impact on students' self-efficacy. It is important that the teaching methods used can improve students' confidence and self-efficacy. This can be achieved if assignments and problems are structured so that they are challenging, and meet Vygotsky's theory on the zone of proximal development [14][15]. The authors have experienced that female students are comfortable with student-centred teaching methods and cooperative learning sessions. However, when traditional lecturing is used, female students are more cautious when asking questions and making comments than male students. The authors have also experienced that female students need more assurance that they are approaching their problems correctly before they start out, eg with their laboratory work.

The aim of this research is to investigate students' initial knowledge of basic mechanics when entering their engineering studies and the confidence levels of their test answers being correct. Also, the study seeks to identify what learning and confidence outcomes can be achieved by applying student-centred teaching methods. The differences in confidence levels between male and female students were also studied. Upon entering their engineering studies, students responded to the Force Concept Inventory (FCI) [16][17]. The FCI is widely utilised among mechanics teaching [18]. The authors complemented the FCI by adding a grid for confidence evaluation [19]. The results of this pre-test are summarised in a previous article (Part 1) [19]. This second part of this research summarises the test results of the post-test that students undertook after attending their *Mechanics 1* course.

SUBJECTS

The subjects of this study were first year engineering students at Tampere Polytechnic in Tampere, Finland [20][21]. There were 107 students who undertook the pre-test [19]. Of this group, 90 students also completed the post-test (see Table 1).

Students who were enrolled in different study programmes included electrical engineering, chemical engineering and textile technology. They were studying their general professional studies such as physical sciences and basic engineering subjects and were taking part in their first physics course called *Mechanics 1*. The course dealt with kinematics, dynamics, the work-energy principle and the impulse-momentum principle of translational motion.

The groups in Table 1 represent students from different educational backgrounds. The students of group 1 studied at a vocational school, having a very limited education in physical sciences, including physics. Students from groups 2 and 3 studied at upper secondary schools. Students with upper secondary school backgrounds were divided into two categories. Students of group 2 studied only a few courses in physics, ie less than six courses, typically only one, which is the mandatory amount of physics courses in the Finnish educational system. Group 3 consisted of students who took six or more courses of physics in the upper secondary school. The background studies of two students remained unknown. Students from group 2 were considered to have a modest background in physical sciences, while students of group 3 were seen to be familiar with the subject.

Table 1: Students' groupings by their educational background.

	Pre-test			Post-test		
	F	M	N	F	M	N
Group 1	11	33	44	10	29	39
Group 2	31	8	39	26	8	34
Group 3	12	10	22	10	7	17
Unknown	2	0	2	0	0	0

Note: F = Female; M = Male; N = Total

WORKING MODE

On the one hand, the choice of teaching methods and arrangements that lecturers make has a clear impact on learning results. On the other hand, if students are not committed and motivated, then there is no guarantee for good learning outcomes. Interactive teaching methods utilised include asking questions frequently, peer interaction, demonstrations combined with peer interaction and Socratic dialogue, and the working method of Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) [22-25]. Also, pre-lecture assignments and traditional homework were engaged [22][26]. All these described methods enabled lecturers to give continuously positive and guiding feedback, and to concentrate their teaching on those issues that were difficult for most students.

The lecturers who were teaching the *Mechanics 1* course consciously started out using a qualitative approach by teaching new phenomena and quantities, after which they proceeded to calculations. This also meant a frequent use of White's elements of memory, such as episodes, images and cognitive skills [27][28]. For example, the theoretical description of motion was visualised through demonstrations compiled with a graphical approach utilising microcomputer-based laboratory (MBL) tools [29]. This has proven helpful in other studies as well [30]. This approach aids students so that they can interpret graphs, such as standard distance-time and velocity-time diagrams. However, students may still have some difficulties in constructing such graphs [31].

Contradictions and cognitive conflicts are the driving forces for the development and learning in many cooperative working processes. If better learning outcomes and enhanced confidence is pursued, then the atmosphere must be positive and be based on self-improvement, rather than a triumph over others. Such an approach should be used so that students feel that they have a mutual goal: learning. All in all, lecturers involved in this study were particular about giving students the feeling that their learning is important. They chose problems and examples that fitted with students' knowledge structures, and were interesting and challenging. The problems could be seen to fit Vygotsky's theory on the zone of proximal development [14][15]. This approach motivated students and gave them a feeling of success, and thus worked towards increasing their confidence levels and their trust in their own abilities.

TESTS AND QUESTIONNAIRES

Students completed the Force Concept Inventory (FCI) at both the beginning and the end of the course [16]. The FCI had been complemented with a grid for confidence evaluation, ie students evaluated their confidence in every question using a scale from one to four (1 = very unsure, a mere guess; 4 = absolutely sure) [19]. When students were asked about their ideas concerning physics teaching and how they would wish that they be taught in the future, they expressed that physics teaching should be practical, things should be visualised and elucidated, and that examples should be used and be interesting.

One of the student groups (chemical engineering) was a target of observations and this student group also undertook the Felder-Soloman Index of Learning Styles test [32]. They also attempted Guglielmino's Self Directed Learning Readiness test [33]. Students and the lecturer were given their test results, along with a feedback and a tutoring session on learning styles and strategies, as well as on self-directed learning readiness. This group also answered an introductory questionnaire at the beginning of the course, a mid-term questionnaire and a feedback questionnaire at the end of the course [26].

RESULTS AND DISCUSSION

Figures 1 and 2 represent the confidence distribution of the correct answers in the FCI for all students. Figure 1 includes the results of the pre-test, while Figure 2 displays the results of the post-test [19]. The results of the post-test, concerning students' knowledge on subject matter, were a slight disappointment to the lecturers. However, it must be noted that the course, *Mechanics 1*, does not cover all topics included in the FCI and that the lecturers did not give the correct answers after the pre-test, and did not specifically prepare the students for the post-test.

Students were asked to predict their success in their course examinations in *Mechanics 1* just prior to the examination results being given. Most students were able to predict their result to some extent, but they all anticipated their scores to be too low; female students were always far more pessimistic than their male counterparts. The final marks were correlated with students' activity in carrying out their homework and pre-lecture tasks, as well as their activity in attending the lectures and participating in the interaction. Students' skills and knowledge in the subject matter was as good as, or slightly better than, previous years. There were no significant differences in the actual marks achieved by female or male students.

Figures 3 and 4 include the confidence distributions of all answers showing the results for female and male students separately. Figure 3 contains the confidence distribution of the pre-test [19]. Figure 4 contains the confidence distribution of the post-test.

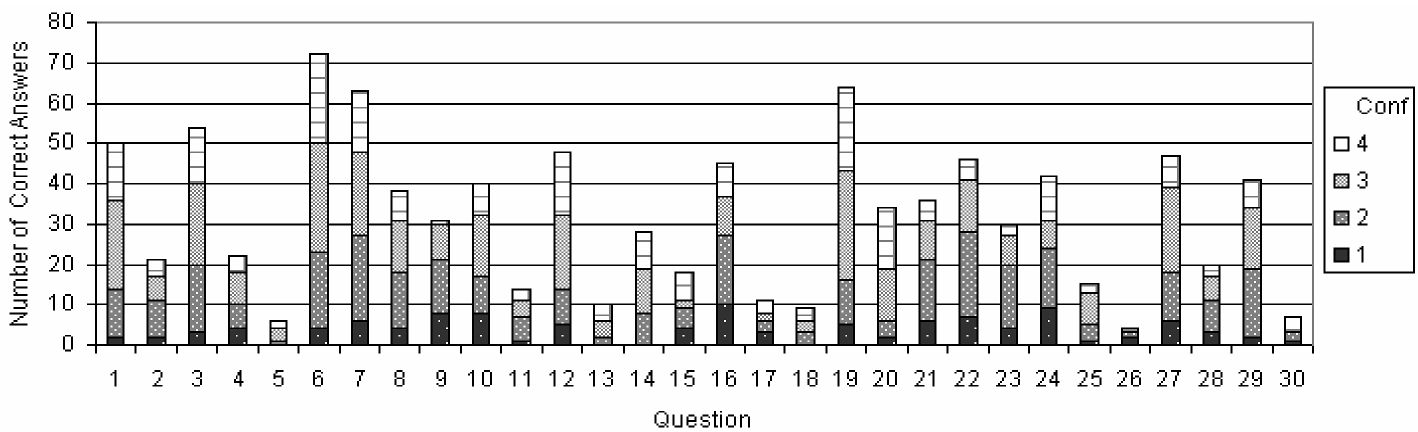

Figure 1: Students' confidence in the pre-test in the case of correct answers in the FCI [19].

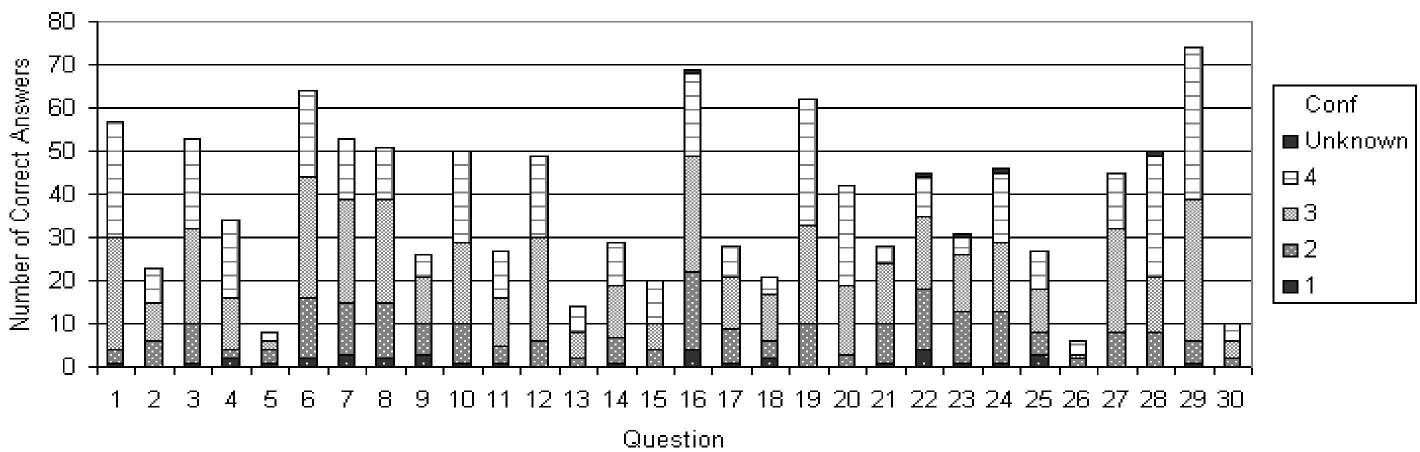

Figure 2. Students' confidence in the post-test in the case of correct answers in the FCI.

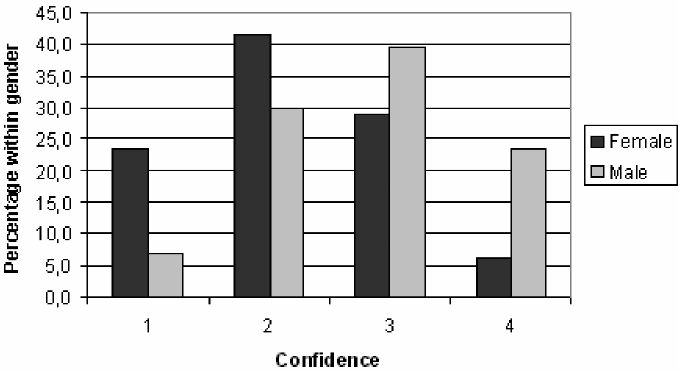

Figure 3: Confidence distribution by gender in the pre-test [19].

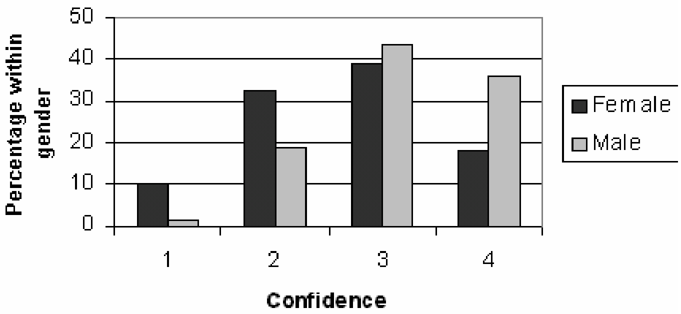

Figure 4. Confidence distribution by gender in the post-test.

It is evident that confidence levels increased for both male and female students. Male students still have a better reliance on their own abilities than female students. It can be seen that male students used high confidence evaluations, ie 3 and 4, in 80% of their answers, while female students, respectively, only used high confidence evaluations in 57% of their answers.

If the changes in the number of the higher confidence evaluations (3 and 4) are compared, it can be seen that the increase has been 17 percentage units for the male students and 23 percentage units for the female students.

Table 2 and Figures 5 and 6 show that 90 students who participated in this study produced 1,143 correct answers in the post-test, of which female students produced 44% and the male students 56%. The gender distribution of all given correct answers remained similar to the pre-test (45%/55% in the pre-test). Of these correct post-test answers, 411 were given with the confidence evaluation 4. This is about twice as much as in the post-test. The percentage of the correct answers with a confidence evaluation of 4 given by female students was 28% and by male students 72%. It can be seen that the male students produced the clear majority of all given correct answers with a confidence evaluation of 4. However, when compared with the pre-test, the female students had improved by 10 percentage units.

Figures 5 and 6 show the confidence distributions of the correct answers given by female and male students. Figure 5 contains the confidence distribution of the correct answers in the pre-test [19]. Figure 6 exhibits the confidence distribution of the post-test.

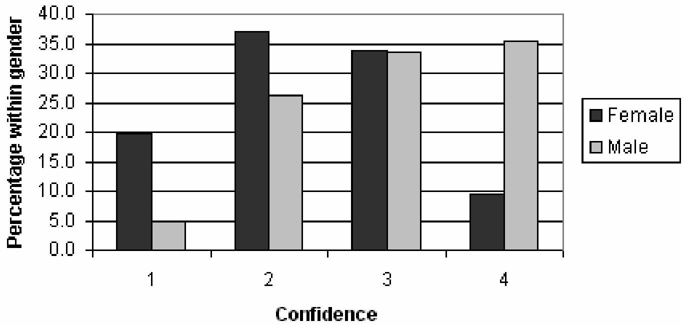

Figure 5: Confidence distribution of correct answers by gender in the pre-test [19].

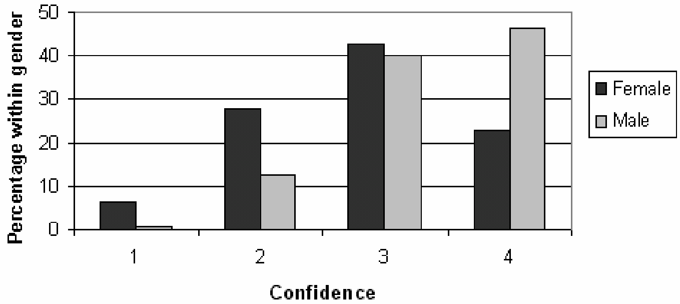

Figure 6: Confidence distribution of correct answers by gender in the post-test.

Table 3 lists the correct answers by educational background and gender. It shows that the number of given correct answers increased in every educational group and that the number of correct answers is well in line with the gender distribution within the group. By observing the differences between the pre- and the post-tests, it can be seen that most changes occurred in the lowest educational group and in the group of male students of group 2.

The number of correct answers with a confidence evaluation of 4 is presented in Table 4. The number of correct answers given with the confidence evaluation of 4 increased in every educational group. Most changes occurred among the male students of groups 1 and 2 and the female students of group 3.

Table 5 shows the proportion of correct answers given with a confidence level of 4 in the pre- and post-tests and the change. It can be observed that both male and female students increased their proportion of correct answers with a confidence evaluation

Table 2: Students' confidence levels regarding the correct answers.

Confidence Level	Female		Male		Female (%)		Male (%)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	86	31	26	5	19.7	6.2	4.9	0.8
2	162	139	138	81	37.1	27.8	26.1	12.7
3	148	214	177	256	33.9	42.8	33.5	40.2
4	41	116	188	295	9.4	23.2	35.5	46.3
Unknown		3		3				

Table 3: The educational group distribution of the number of correct answers.

Group	Students' Gender (Pre)/(Post)	Correct Answers		Correct Answers per Student		Change in the Number of Correct Answers per Student
		Pre	Post	Pre	Post	Post – Pre
Group 1	Male (33)/(29)	296	393	9.0	13.6	4.6
	Female (11)/(10)	61	107	5.5	10.7	5.2
Group 2	Male (8)/(8)	78	112	9.8	14.0	4.3
	Female (31)/(26)	235	251	7.6	9.7	2.1
Group 3	Male (10)/(7)	162	135	16.2	19.3	3.1
	Female (12)/(10)	127	145	10.6	14.5	3.9

Table 4: The educational group distribution of the number of correct answers with the confidence evaluation of 4.

Group	Students' Gender	Correct Answers with a Confidence Evaluation of 4		Correct Answers (Confidence Level of 4) per Student		Change in the Number of Correct Answers (Confidence Level of 4) per Student
		Pre	Post	Pre	Post	Post-Pre
Group 1	Male	90	168	2.7	5.8	3.1
	Female	2	20	0.2	2.0	1.8
Group 2	Male	24	59	3.0	7.4	4.4
	Female	19	45	0.6	1.7	1.1
Group 3	Male	74	68	7.4	9.7	2.3
	Female	16	51	1.3	5.1	3.8

Table 5: Proportion of correct answers given with the confidence of 4 in the pre- and post-tests by educational background and gender.

Group	Students' Gender	Proportion of Correct Answers Given with a Confidence Level of 4 (%)		Change (%)
		Pre	Post	Post - Pre
Group 1	Male	30.4	42.7	12.3
	Female	3.3	18.7	15.4
Group 2	Male	30.8	52.7	21.9
	Female	8.1	17.9	9.8
Group 3	Male	45.7	50.4	4.7
	Female	12.6	35.2	22.6

of 4, but female students had a clearer improvement. This is congruent with the studies of Metz et al, who studied students in technical fields and the gender differences in areas related to self-confidence and self-esteem [3]. They reported that both male and female students show higher levels of self-confidence with each successive class level, but that women never catch up. Even in group 3, which consists of students with the highest background of studies in physics, the percentage of the correct answers with the confidence evaluation 4 has almost tripled.

Many studies have shown that female students rate their engineering related social activities higher than males and that female students have a very positive attitude towards cooperative working, study groups and professional societies [3][34][35]. The present study verifies this. It can also be seen that those students, who had a somewhat modest background in their physics studies, benefited from the applied student-centred teaching methods. Both the feedback questionnaire and the authors' observations showed that students liked the interactive approach and found working in pairs and small groups very useful. Students took responsibility and appreciated the opportunity to work with their peers under the presence and guidance of their lecturers.

SUMMARY

The central issue in this research was students' active working in groups and studying how the application of student-centred teaching methods could help students to learn better, and build their confidence and ability to evaluate their knowledge. Students were given concrete problems to work on that they could solve with the help of their peers, thereby acquiring feelings of being able to achieve results and success. The problems were chosen so that they would fit the groups' zone of proximal development. They gained constructive feedback on a regular basis in a positive and constructive manner. They built new knowledge on the basis of their prior knowledge and experiences. The studied concepts and phenomena attained meaning due to this kind of an approach and made the transfer from the macro world to the symbolic world easier for students. They were able to augment their confidence and increase their motivation levels.

When considering the ratio of correct and incorrect answers evaluated at the confidence level 4, we must be somewhat worried. After the course, students' evaluations of their knowledge are still too optimistic. In general, all students increased their confidence and their subject matter knowledge has improved. However, more study needs to be conducted on the reasons for their misconceptions, eg why the dominance theory is held so strongly in their minds, easily leading (quite wrongly) to high confidence evaluations. Overcoming students' misconceptions is a true challenge and, thus, persistent efforts need to be undertaken by pedagogical means to achieve this in order to improve learning. As educators, we must emphasise to students that they have to consciously work towards building meaningful cognitive structures by attending and taking time to organise and integrate their new achieved knowledge with their prior knowledge structures, and to constantly be critical about the *correctness* of their prior knowledge.

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