

Good practice report

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How to open inquiry teaching? An alternative teaching scaffold to foster students' inquiry skills

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Abstract:

Students are expected to learn scientific inquiry. It consists of several individual processes that need to be coordinated. Recent teaching concepts have suggested fading students into a limited set of interconnected processes, mostly using backwards-fading techniques. The efficiency of open approaches to learning has been criticized repeatedly in science education research. Following a brief discussion of previous scaffolded inquiry teaching concepts developing students into "open inquiry", it is argued that these have been interpreted too strictly in science classrooms: (i) restricting inquiry to too few processes; (ii) delivering support to students in an all-or-nothing fashion; (iii) understanding opening of inquiry as a one-way-street insensitive to needs of momentary closing. This is not justified by the situated character of pedagogical considerations that depend on learners' needs and potentials, teachers' strengths and insecurities, and potential constraints from content. An alternative matrix for teaching inquiry is suggested that distinguishes five processes in four variations of openness. An example from chemistry shows that the achieved degree of openness is derived from situated considerations and is not ruled by *a priori* decisions on openness. Nor is this decision governed by faithfully adhering to a schematic sequence (confirmatory → structured → guided → open inquiry).

Keywords: guided inquiry, open inquiry, scaffolding, scientific inquiry, structured inquiry

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Introduction

"Teaching science as inquiry" (Schwab, 1960) has been *en vogue* in science teaching for the past half century. It has been criticized almost as long. While most science educators agree that enabling students to inquire self-directedly into science issues is desirable, research is divided in how far this can be achieved (cf. Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006). Inquiry, in science education, can be viewed from different perspectives: on behalf of the learners it can be considered a way of problem solving; they need to be introduced to this way and, hence, the term "inquiry" can designate an instructional approach which enables students to use inquiry and to achieve scientific knowledge by it. Typically, an idealized inquiry process is suggested which students are faded into through scaffolded learning opportunities (cf. Schwab, 1966), e.g. by teaching with guided or structured inquiry settings (Bell, Smetana, & Birns, 2005). Students are introduced to the inquiry process taking them by the hand, allowing more "give" to the lead as time progresses until they can go through the complete process self-directedly. Some studies show scaffolded approaches to be beneficial (cf. Anderson, 2002; Bruder & Prescott, 2013; Wolf & Fraser, 2008), some are contradictory or inconclusive in their results (cf. Green Miller, 2014). This paper will argue that there have been some crucial misunderstandings in opening inquiry teaching using scaffolding at the secondary level with regard to (a) the process's complexity, (b) the necessary degree of teacher-assistance, and (c) the faithfulness with which to implement a scaffold. An alternative matrix to informing the opening of inquiry teaching is suggested and illustrated with a chemistry experiment. This is meant as an exemplary approach, not suggesting that the matrix is exclusively useful to chemistry teaching.

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Inquiry, scientific inquiry, experimentation: the same difference?

The terms inquiry, scientific inquiry, and experimentation, respectively, sometimes appear to be used in free variation. Generally speaking, "inquiry" should relate to *all* methods of extending knowledge driven by a question, expectation, or hypothesis (i.e. including methods of hermeneutic text analyses or compositional analyses in art). For methods specific to the sciences (biology, chemistry, and physics) the term "scientific inquiry" should be used – i.e. as a sub-set of inquiry which embraces, e.g. observation, modelling, or experimentation. Thus, experimentation should be understood as merely one realization from the plethora of methods to extend knowledge driven by questions, expectations, or hypotheses in the sciences. As this paper is exclusively concerned with inquiry teaching in science education, reference to "scientific inquiry" will – in concord with much of the referenced literature – be shortened to "inquiry" for readability's sake.

Since experimentation forms one face of inquiry (NRC, 1996, p. 23) and is often considered essential in the natural sciences (Kirschner, 1992, p. 275), an approach toward the wider concept (inquiry) from its exemplary realization in science classes is reasonable. Experimentation's prominent position within inquiry (e.g. Rönnebeck, Bernholt, & Ropohl, 2016) makes it a suited launching site for students to further probe into other inquiry methods (e.g. scientific modeling, observation, simulation). This paper will exemplify inquiry activities in an experiment – for this reason, much of the argumentation draws on illustrative examples from experimental inquiry.

At the same time, the reader is advised to keep in mind that inquiry can be interpreted in several ways: (a) to describe scientific ways of knowing, (b) a way for students to learn science, (c) an instructional approach, and (d) to characterize curriculum materials (Furtak, Seidel, Iverson, & Briggs, 2012, p. 304). These aspects are not wholly independent of each other and considerations of the one aspect will necessarily influence an understanding of the other aspects. This paper is primarily concerned with meaning (c) suggesting an explicit *inquiry teaching approach*. Yet, as it is directed at fostering *inquiry learning*, meaning (b) cannot be ignored or muted and will, thus, shine through now and again.

"Inquiry teaching" here describes an instructional approach explicitly directed at supporting students to achieve inquiry learning – it, thus, has to be differentiated from teaching *through* inquiry (e.g. Jiang & McComas, 2015, p. 555) in which students are expected to gather the inquiry process implicitly. The present understanding entails more than just introducing students to a stepped approach of doing inquiry in hands-on-activities. Students need to *do* inquiry but they also need to *reflect* on what they have done and why they have done it in a particular manner; inquiry teaching to achieve inquiry learning needs to provide room for these activities allocating sufficient lesson time for this in their preparation.

Inquiry as a corner stone of science education

Most concepts of scientific literacy depict inquiry as an epistemological process in science education to uncover scientific knowledge through interaction with natural phenomena – e.g. Gagné's (1965) "Process Skills", Bybee's (1997) "Conceptual and Procedural Scientific Literacy", the AAAS's (1993) "Benchmarks for Science Literacy regarding Scientific Inquiry"; PISA's "Evaluating and Designing Scientific Enquiry" (OECD, 2019), or the recent US National Science Education Standards (NRC, 1996). Inquiry is considered a shared concept between school's scientific disciplines (i.e. biology, chemistry, and physics) while remaining flexible towards their individual emphases: biology lessons might focus more on observation, physics instruction might pay extra attention to issues of measurement, and chemistry teaching might take a more qualitative view point on its objects of inquiry. This simultaneously unifying and differentiating character of inquiry challenges science educators to introduce the rich process into classrooms and has led to inquiry competences being integrated internationally in science curricula (e.g. Abd-El-Khalick et al., 2004; ACARA, 2016; CPDD, 2000; DfE, 2014; EDK, 2011; KMK 2005a; 2005b; 2005c; MoE, 2007; NRC, 2011).

Inquiry-based teaching can address procedural, content, or epistemic aspects of science education, respectively (cf. Hodson 1996; 2014; Vorholzer & Aufschnaiter, 2019) and teachers need to decide which of these to address in their lessons. An experiment on natural acid-base-indicators (e.g. red cabbage) can serve to introduce (1) the logic of inquiry when trying to identify which from a choice of substances is an acid (procedural), (2) the concept of acids as a class of substances (content focus), or (3) the limitations of red cabbage as an indicator which cannot differentiate well between acids of different pH (epistemic).

Inquiry as a disputed teaching approach

Inquiry has been prominent in school science for almost 200 years (DeBoer, 2006), and it has been criticized for almost as long (e.g. Dewey, 1910; Hodson, 1996; Hofstein & Lunetta, 1982). “Open inquiry” as an effective way of acquiring new knowledge giving students responsibility for the complete process (cf. Bell et al., 2005), is considered the ultimate goal of inquiry teaching. Doing inquiry combines learning scientific content knowledge with learning process skills (e.g. Banchi & Bell, 2008); this goal has often *not* been met:

- Mayer (2004) reviews four decades of discovery-learning related research and emphasizes that it has been known for a long time that guided teaching approaches are more effective for facilitating learning processes than open approaches,
- Kirschner et al. (2006), Klahr and Nigam (2004), and Sweller, Kirschner, and Clark (2007) claim that teaching which is opened too early or too wide is ineffective with regard to learning due to cognitive overload on the students,
- Hmelo-Silver et al. (2007) advocate for the inclusion of scaffolds in teaching to support students in otherwise inefficient problem-oriented learning, inquiry learning, respectively,
- Settlage (2007) concludes from a lack of empirical evidence in favor of open inquiry teaching that it is a “Sisyphean task: pointless and misguided” (p. 466) aligning him with Mayer’s (2004) verdict,
- Blanchard et al. (2010) feel that denoting open inquiry as the “ideal” way to teach science” is misleading as it does not take into consideration the idiosyncratic “classroom context and the demands of the material” (p. 582), i.e. they capitalize on the situated character of educational decisions when teaching.

There appears to be consensus, however, that inquiry (as a way of learning) cannot be accomplished by mere observation (Bell, Blair, Crawford, & Lederman, 2003), nor are too narrowly guided laboratory experiences conducive (e.g. Gagné, 1965).

Supporting inquiry

Conveying scientific inquiry competences requires teaching approaches that enable hands-on experience and repeated practice as well as reflection phases with the teacher (e.g. Bell et al., 2003; Klahr & Nigam, 2004) as doing inquiry combines the learning of scientific content with the learning of scientific process skills (e.g. Banchi & Bell, 2008); these approaches negotiate between closed and open inquiry allowing for cumulative learning. Relating hands-on activities to an understanding of the process is encouraged by e.g. building scaffolds that can be deconstructed once the learner becomes more proficient in the epistemological process (e.g. Hmelo-Silver et al., 2007). More closed inquiry may give the opportunity to explain and discuss the inquiry process, more open inquiry can engage students in scientific reasoning, in the inquiry activities as such, and following the activities in reflecting the inquiry process. A scaffold, here, is understood as being “construed as support given by a teacher to a student when performing a task that the student might otherwise not be able to accomplish” (van de Pol, Volman, & Beishuizen, 2010, p. 274), i.e. a scaffold is the teacher’s tool to support student learning. Consequently, scaffolding can be interpreted as “teaching method that can focus on the development of the child” (van de Pol et al., 2010, p. 275). This paper introduces a matrix for designing inquiry activities understanding scaffolding as a teaching method which might address learning challenges for whole groups of learners, not ruling out that it might be used for individual student scaffolding. Thus, a differentiation between inquiry teaching [perspective (c) – s. above] that uses scaffolding to support inquiry learning [perspective (b)] borders the impossible as the one is the means to achieve the other.

When learning to ride a bike, training wheels or the parent’s helping hand are removed once the child can keep her balance – a good scaffold in science education, by analogy, should similarly support students in learning a process: when they can perform self-directedly, e.g. drawing conclusions from experimental evidence, instructional aids can be faded from the teaching (cf. van de Pol et al., 2010). Teachers might start these fading processes, e.g. by no longer cueing students to formulate a conclusion. Most scaffolds introducing inquiry processes suggest backward-fading strategies, i.e. to deconstruct the scaffold back-to-front. These strategies have been shown to be effective in learning with worked-examples (Renkl, Atkinson, Maier, & Staley, 2002) and are expected to work in scaffolding inquiry by analogy (cf. Slater, Slater, & Shaner, 2008). This rationale has led to the introduction of ‘staircase scaffolds’ of inquiry (e.g. Bell et al., 2005) which are climbed – in a faithful reading:

one step at a time – encouraging students to increasingly take responsibility for the process the more familiar they get with its workings.

Reviewing scaffolding approaches in inquiry teaching appears to hide in the shadows of current science education research. Often – the authors do not except themselves from this observation – an already existing scaffold is taken on by face value. Should problems or inconsistencies arise from its use, these are not addressed nor channeled into an improvement of the scaffold. More – and more differentiated – research is necessary to understand how inquiry teaching might effectively be opened using scaffolds, the results of which might eventually give a more complete picture of what makes proficient students of science (see also Vorholzer & Aufschnaiter, 2019).

Scaffolds for inquiry

The challenge to convey an adequate image of inquiry to students is anything but novel and the multitude of suggested scaffolds share a structural basis: Schwab (1966) suggests teaching “science as inquiry” in order to produce proficient scientists, able policy leaders, and an informed public. He advises to introduce students ascending through three cumulative levels of openness that differ in whether a task provides problem and method (level 1), only the problem (level 2), or none of these (level 3), respectively (Schwab, 1960, 1966). Herron (1971) adopts the approach adding a “zero level” which provides all the aspects of inquiry (problem, method, and answer).

Bell et al. (2005) built a prominent scaffold to advance students’ inquiry learning on an analogous three-stepped process (question – method – solution; see also Banchi & Bell, 2008) yielding these four hierarchical levels of inquiry: (1) confirmation inquiry (everything provided) – (2) structured inquiry (students derive solutions) – (3) guided inquiry (students design investigations and derive solutions) – (4) open inquiry (everything done by students). Several authors share this model (verification inquiry, structured inquiry, guided inquiry, open inquiry; e.g. Abrams, Southerland, & Evans, 2007; Blanchard et al., 2010), but various finer grained descriptions of the inquiry processes have been proposed (cf. Emden & Sumfleth, 2016; Friedler, Nachmias, & Linn, 1990; Jiang & McComas, 2015). At its most complex, Pedaste et al. (2015) differentiate inquiry into five “general inquiry phases” which are made up of eleven “prospective phases” which again fall into 34 “inquiry activities”. Their underlying logic suggests that one first needs to master single inquiry activities which can only be generalized into fewer “general inquiry phases” over time. Thus, students need to be introduced to concrete activities supporting them concurrently in building generalizations. The only consensus on how many steps the inquiry process is composed of appears to be that it can be no fewer than three (cf. Emden & Sumfleth, 2016); probably, 34 individual activities are too many for pragmatic tuition in inquiry. But how many *is* pragmatic and reasonable? And how can students be advised to generalize an abstract process from their exemplary endeavors into inquiry?

Limitations of scaffolded open inquiry

The preceding sections have drawn attention to several crucial aspects that need to be considered when opening the teaching of inquiry: the complexity of the process, the degree of necessary teacher assistance, and the faithfulness to a scaffold. So far, research suggests that inquiry processes might have been opened too early in instruction creating unjustified cognitive demands so that students underperformed (Vorholzer & Aufschnaiter, 2019). Yet, Mayer’s (2004) call for a “three-strike-rule” on banning discovery from science classrooms might have been somewhat precocious because there are possible reasons for an observed under-par-efficacy which can be addressed to eventually make open inquiry schemes work:

- i. *process-complexity*: the often suggested three process-aspects (e.g. Abrams et al., 2007; Bell et al., 2005; Blanchard et al., 2010) are cut too coarsely thus being inherently too complex for students to master; i.e. the inquiry processes needs to be further differentiated (cf. Pedaste et al., 2015) with each “new” aspect bringing their own learning challenges;
- ii. the degree of *teacher-assistance* might have been negatively affected by reading scaffolds for inquiry too narrowly; thus, the choice for teacher-assistance was limited to “sink-or-swim”: either “the teacher presents” or “the student finds” instead of a more mediating “the teacher helps to formulate” – Vorholzer and Aufschnaiter (2019) apparently share this critique and suggest student autonomy to be a *continuous* – not a *dichotomous* – dimension along which inquiry teaching can be differentiated;

- iii. scaffolds might have been implemented with exaggerated *faithfulness* (a) interpreting them to prohibit returning to more closed formats once advanced inquiry levels have been reached; this usually is an implicit understanding as only few scaffolds address this issue openly (e.g. Mayer & Ziernik, 2006); (b) disallowing alternatives to back-to-front-fading while there is no evidence that this is a valid strategy in inquiry, too.

Resolving misunderstandings in a matrix for inquiry teaching

While we agree on the basic premises that (i) inquiry is a complex process that is composed of a finite set of interlinked subprocesses, and (ii) that opening the complex process of inquiry needs prolonged assistance from the teacher, and (iii) teaching inquiry can profit from some sort of structuring aid, we challenge these associated assumptions:

- i. **Three sub-processes form a sensible set to work with in science classes, especially regarding inexperienced learners:** more sub-processes bear the potential of clarifying the specified cognitive operations otherwise being glossed over in a single head-term (e.g. asking questions is different from formulating an hypothesis) – at the same time, care needs to be taken not to over-differentiate between processes or students run the risk of getting lost in too many, minutely disjointed steps;
- ii. **support in opening inquiry is “sink-or-swim”:** the processes to be mastered are too complex for students to grasp them “in one go”, they need protected time to familiarize themselves with the processes; in this, finer gradations of support need to account for diverse student needs – sometimes, affirmation is all they need, at other times a complementary explanation or a “nudge” into the right direction; teachers need not unravel everything just because students got slightly stuck (“Think again. Remember, when we ...” might already do the trick);
- iii. **opening inquiry is a one-way-street:** regarding the pedagogical triangle, teaching decisions always need to be situated considerations which simultaneously take potentials and limitations of students, teachers, and content into account (Bertrand & Houssaye, 1999; Friesen & Osguthorpe, 2018; cf. “contingency” in van de Pol et al., 2010); therefore, opening inquiry must be reversible on principle: some inquiry activities require increased assistance of the teacher as students do not have the necessary background knowledge; moreover, potentially hazardous inquiry activities can conflict with teachers’ own legitimate wish for security (they might be held accountable for accidents) etc.; moreover, in the process of opening inquiry teachers should be encouraged to resort to more directive ways of instruction when they realize that this is necessary.

Process complexity

How many steps do sufficiently scaffold inquiry? How many steps is too many, too few, respectively? Relying on a synthesis from previous suggestions (Friedler et al., 1990; Jiang & McComas, 2015; Mayer & Ziernik, 2006) a differentiation into five subprocesses is suggested for adoption in a matrix for inquiry teaching (see Figure 1). Formulating questions (1) is distinguished from formulating hypotheses (2) to account for the distinct epistemic roles both these processes play (question: opening an inquiry horizon, hypotheses: narrowing down the horizon to allow for an operationalizable investigation). Designing and executing (3) an inquiry are merged in this matrix, as faulty execution of an inquiry – regarding experimentation – often is indicative of insufficient psychomotor skills (*mistakes* by chance or oversight) while inadequate design speaks of systematic *errors* with respect to cognitive conceptualizations; it is the latter that current science education is primarily concerned with and so the matrix emphasizes the design over the execution process. Analyzing (4) qualitative data (observations) and quantitative data (measurements), which might still rely very much on “objective” disciplinary heuristics and methods (e.g. building hierarchies, deriving categories, tabulating and graphing data), needs to be distinguished from an interpretation of the data (cf. Mayer & Ziernik, 2006). The latter necessarily involves the interpreter’s prior knowledge and subjective understanding to arrive at a conclusion (5). On principle, any inquiry might halt at this process as its *raison d’être* is achieved: knowledge has been generated. Applying results or making predictions (cf. Friedler et al., 1990) might be considered extensions of the initial five processes and, therefore, are disregarded in this matrix.

	0 closed	1 moderately opened	2 opened	3 open
Question	Learners engage in a provided question	Learners select from a choice of questions	Learners develop question with support (verbal or medial)	Learners develop own question
Hypothesis	Learners engage in a provided hypothesis	Learners select from a choice of hypotheses	Learners develop hypothesis with support (verbal or medial)	Learners develop own hypothesis
Design inquiry	Learners work with provided instructions (‘cook book’)	Learners select from a choice of instructions	Learners design an inquiry with support (verbal or medial)	Learners develop an own design
Analysis	Learners analyze data according to a script, pattern, example	Learners select from a choice of data representations (e.g., table, bar graph, scatter plot)	Learners analyze data with support (verbal or medial)	Learners choose their own analysis of data
Conclusion	Learners discuss a provided conclusion	Learners select from a choice of provided conclusions	Learners develop conclusion with support (verbal or medial)	Learners develop own conclusion

Teacher-directedness

Student-directedness

Figure 1: A two-dimensional matrix for inquiry teaching [adapted from Baur, Hummel, Emden, & Schröter (accepted)].

Teacher-assistance

How can teachers assist students in mastering the processes? NRC (2000) suggests four variations for each of its five essential inquiry features negotiating between teacher/material- and student-self-direction. These variations are adopted to the five-stepped process structure suggesting increasingly student-centered approaches to the teaching of inquiry processes. Thus, a two-dimensional matrix for teaching inquiry (Figure 1) is derived.

Faithfulness

The matrix is not to be read as a “linear fading tool” which increases the degree of openness by mechanically shifting responsibility to the learner. Teachers are encouraged to decide anew for each given inquiry problem, for each of the processes individually how open it could and should be delivered to their students. Moreover, the matrix – as an essential novelty – explicitly allows for differing settings *between* the processes if situated consideration in accordance with the pedagogical triangle suggests this.

How open is the teaching?

An overall degree of openness might be estimated from the processes’ individual settings rather than from a superimposed stage-pattern (cf. Bell et al., 2005): arguably, there are inquiry problems which students cannot fully plan and execute self-directedly (e.g. for safety reasons, unfamiliarity with equipment, or considerations of classroom management). Reasons for this, however, do not necessarily prevent students from developing their own questions, autonomously formulating hypotheses, analyzing data self-directedly or arriving at conclusions on their own. As Bell et al. (2005) do not envisage situations such as these, they can provide no viable scaffolding here. The matrix’s advantage is apparent: allowing to close inquiry teaching just on “Design inquiry” (Figure 1) leaves four more processes to be kept open and could so lead to inquiry teaching with increased degrees of student-centeredness at the beginning *and* at the end. The matrix, thus, returns more degrees of freedom to the teacher when planning inquiry instruction. Notwithstanding this flexibility, the ultimate goal of science education is having the settings on each of the processes be as advanced as possible.

Example activity

This section will outline how the matrix can inform teaching inquiry with a chemistry experiment. Settings of openness are argued only with respect to students’ differing potentials always assuming a teaching situation with 14- to 16-year-olds who have had some basic introduction to chemistry (e.g. chemical reaction, acids and

bases, hands-on experience). Depending on local regulations, the handling of concentrated acid solutions ($w = 0.2$) might necessitate more closed settings on design. Likewise, differing teachers' confidences with this kind of experiment might lead to different settings in the matrix – not everybody is equally at ease to have students (or: *all* the students) handle concentrated acid solutions even if it is technically allowed. Let it be emphasized: the matrix cannot (and does not intend to) substitute for a situated decision – this is the chemistry teachers' professional domain. The matrix tries to support their decisions by providing a pattern for orientation – it lies with teachers alone to seize that offer.

Task: Students investigate factors influencing the rate of reaction between ethanolic acid (CH_3COOH) and sodium bicarbonate (NaHCO_3). They are given two solutions of vinegar (5 % and 20 %) and two preparations of sodium bicarbonate (powder and tablets). The reaction between these can be interpreted as a Bronsted-acid-base reaction in which carbon dioxide forms. Given controlled solution volumes and masses of bicarbonate, the rate of reaction is dependent on (a) the acid concentration, (b) graininess of the bicarbonate, (c) temperature of the acid solutions.

Most students will probably not come up with their own **questions** (level 3) for lack of every-day experience on which to draw. This process's setting might typically be level 0 (heading on the blackboard: "Which factors influence the rate of reaction?"). However, students might be triggered to formulate a question by presenting them with the apparatus and the chemicals (level 2 – "Which questions can we answer using these things?"); they might be encouraged to inquire about the reaction products, the speed or the heat of reaction etc. by giving them a word list with those concepts they are familiar with ("Choose one of the concepts and formulate a research question that you wish to investigate."). Alternatively, the teacher might suggest a selection of questions focusing on e.g. either one of the factors ("Does it make a difference if we put powder of bicarbonate in table vinegar or in spirit vinegar?"), a combination of two, or of all three of them (level 1). The investigation's subsequent course hinges on how the teacher plans to react to the number of surfacing questions (just allowing one to be studied, allowing all).

Students might **hypothesize** by association ("I know from ...; I have seen/read in ...") about an influence of temperature or concentration (level 3). Teachers can present the chemicals in their respective preparations from which students assume that either the reactants' concentration or/and graininess are relevant (level 2). Students can be assigned to different investigations by providing a choice of hypotheses (level 1): e.g. (1) acid concentration, or (2) finer graininess of bicarbonate increases the rate of reaction.

Designing and executing the investigation on level 3 is only possible if relevant apparatus and techniques are familiar – collecting and measuring gas volumes does not come naturally. If, however, teachers emphasize developing inquiry's epistemological logic, they might be content if students' designs include that gas needs to be measured *somehow* – the proper technique then is of secondary importance and can be shown "on demand"; such a scenario might still be considered level 3. Otherwise, teachers can present students with an unstructured choice of lab equipment (level 2) taxing students to select pieces of apparatus and assemble them into a functional station. Difficulty can be increased providing irrelevant apparatus, or not clueing students if everything is needed to set up a functional experiment. A choice of settings, i.e. assembled stations, can be offered in a level 1 scenario: taking reaction time of (1) collecting a defined volume of gas in a pneumatic trough, or (2) until reaction ceases for a defined mass of bicarbonate (see Figure 2–Figure 4).



Figure 2: Choice of lab equipment.

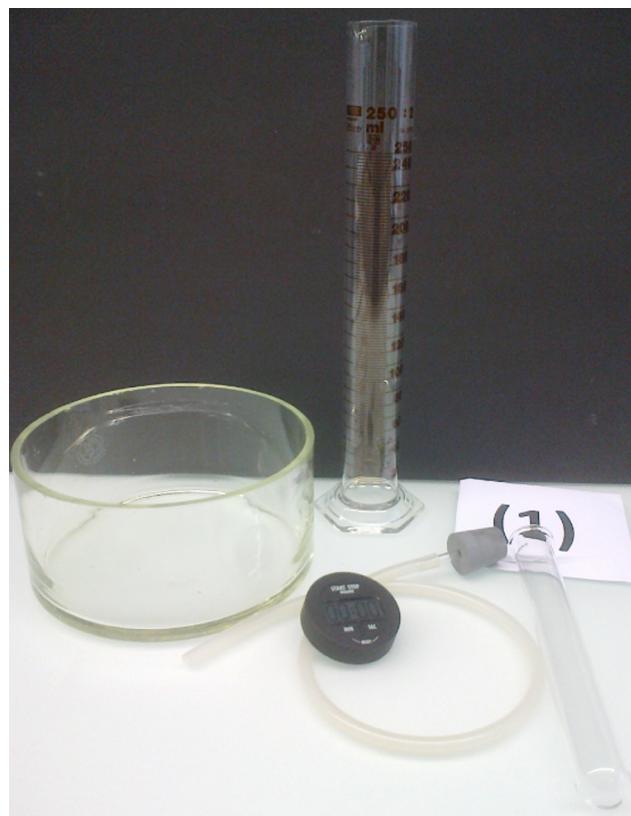


Figure 3: Experiment station “pneumatic trough”.

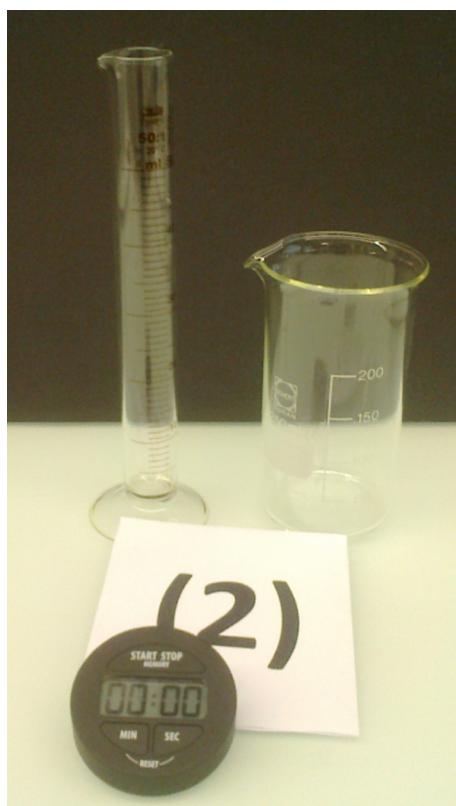


Figure 4: Experiment station “reaction ceases”.

Students can be advised to record data for **analysis** in a traditional format (graph and/or table) to identify trends (level 2); experienced students achieve this unaided (level 3). A level 0 scenario can arguably be beneficial if student results are too diverse to arrive at a consensus. Level 1 analysis might be facilitated by letting students choose and argue for exemplary graphs on basis of their own record (“Which of the following graphs, do you think, was drawn from a similar experiment to yours?”). In this layout students need to review their own data and identify trends in one or more of the suggested graphs – providing several time-volume-graphs with differing inclines representing linear or exponential development (i.e. different reaction orders) can increase the challenge. Admittedly, a level 1 scenario will not always be feasible or pragmatic – especially qualitative inquiry appears challenging to realize on this level. It has been included here to show that it can be realized on principle.

Having identified the main trend in their data, students need to formulate a **conclusion**. Advanced students will accomplish this without assistance (level 3). Yet, many students do not realize that concluding is different from identifying the trend. They need guidance to relate their conclusion back to their hypotheses (level 2): “Your hypothesis was ... Now, what can you say about your hypothesis?” Conflicting sample conclusions can challenge students to decide which is correct (level 1). Again, level 0 might be advisable if data is so diverse that students cannot make sense of it: a sample conclusion is developed with explicit reference to the data (“As you can see, the longer we wait the more gas is produced. This graph, therefore, inclines. With spirit vinegar the incline is even steeper than with regular vinegar: more gas is produced in the same time. We, thus, have learned that the concentration of vinegar influences the rate of reaction.”).

Again: the decisions for each of the processes is made individually and requires the teacher’s deliberation. There is no rule ordering e.g. conclusion to be level 2 or higher if data analysis was level 2. If teachers let students choose from a selection of questions (level 1), they can either leave the rest of the investigation equally or wider open (“How can you follow up on each of your questions?”) or they can narrow options down again (“We want to focus, for today, just on the influence of ...”). Likewise, it is reasonable to assume that teachers, who have chosen to open wide (level 3) on designing and executing, will experience time constraints that need to be counterbalanced by, e.g. narrowing analysis-options (level 1), or even providing students with a paradigmatic problem solution (level 0). As long as these decisions are made deliberately and reflectingly in an education context, they are professional; as soon as they become schematic or detached from context, they are debatable.

Conclusion and outlook

Students are expected to acquire inquiry abilities which can be relevant to their everyday lives. In order to achieve this goal, they need to be provided opportunities to learn, to practice and to become confident in inquiry settings. They need to be allowed time and protective frame to investigate, to make mistakes, to review their processes, and to understand.

The suggested matrix for teaching inquiry can be a valuable tool in planning and designing inquiry teaching for the classroom. It allows for situated adoption of inquiry activities regarding the students' potentials and limitations, the teachers' strengths and insecurities, as well as the restrictions posed by specific content. The more differentiated teachers can adopt inquiry to their students' needs, the more easily it will be possible for students to take over responsibility for these activities. Open it too early and too much: students will almost inevitably be overtaxed (Kirschner et al., 2006; Klahr & Nigam, 2004).

Apart from its value for planning and delivering instruction in inquiry, the matrix can serve as an inquiry *learning scaffold* in professional development contexts. Many teachers confuse inquiry with hands-on and do not realize that inquiry principally denotes *any* methodological approach that is question-driven (e.g. Furtak et al., 2012). They can use the matrix as a scaffold for their own understanding which eventually informs their teaching: having understood once that conclusions need to relate to the hypotheses, they are less likely to miss it in their teaching. On the same note, the matrix can be used to assess lessons on inquiry and to identify developmental potentials for pre-service teachers: by making transparent that they e.g. did not differentiate between question and hypothesis or that designing an experiment can be tentatively opened by offering a select set of materials. Applying the same matrix to student performance could likewise discover fostering potentials when fading students into inquiry: realizing that students cannot formulate an hypothesis does not necessarily entail to provide them with a sample solution but might already be remedied by offering them strips of text from which they can reconstruct an hypothesis (like a jig-saw, cf. Figure 5). These potential uses all focus on an in-class administration of the matrix. Yet, that is not where it ends. We can picture the matrix as a basis for video-analysis of inquiry lessons as well as a paradigm to identify levels of competency in inquiry teaching.

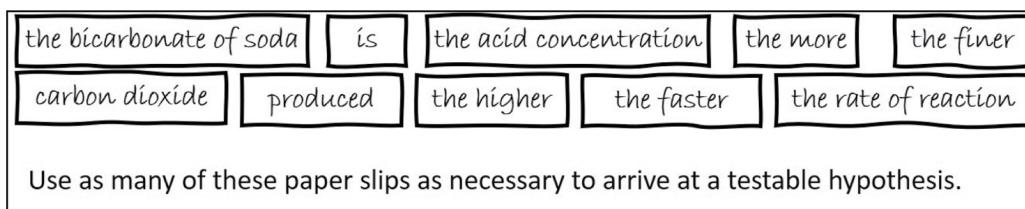


Figure 5: Jig saw to support the formulation of hypotheses. Idea and design: A. Baur, M. Emden

For all the purposes mentioned, the matrix's potential derives from its flexible use towards the situated character of teaching making it thereby more of a descriptive instrument than a prescriptive book of rule. If anything might be learned from the decades of research on inquiry teaching, it is that too narrow guidance is not beneficial – thus, the narrowing logic of a prescriptive scaffold might not be the ideal remedy when it comes to situated decisions. Therefore, an alternative pathway via the more flexibly employable matrix is encouraged – after all, if reality does not conform with the instrument, which of the two could change?

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