# Student-Generated Stop-Motion Animation in Science Classes: a Systematic Literature Review

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## Abstract

In recent years, student-generated stop-motion animations (SMAs) have been employed to support sharing, constructing, and representing knowledge in different science domains and across age groups from pre-school to university students. The purpose of this review is to give an overview of research in this field and to synthesize the findings. For this review, 42 publications on student-generated SMA dating from 2005 to 2019 were studied. The publications were systematically categorized on learning outcomes, learning processes, learning environment, and student prerequisites. Most studies were of a qualitative nature, and a significant portion (24 out of 42) pertained to student teachers. The findings show that SMA can promote deep learning if appropriate scaffolding is provided, for example, in terms of presenting general strategies, asking questions, and using expert representations. Also, the science concept that is to be presented as a SMA should be self-contained, dynamic in nature, and not too difficult to represent. Comparative quantitative studies are needed in order to judge the effectiveness of SMA in terms of both cognitive and non-cognitive learning outcomes.

**Keywords** Modeling-based learning · Student-generated animation · Stop-motion animation · Slowmation · Science learning

## Introduction

Visual representations have been reported to contribute to the development of students' learning of science (Evagorou et al. 2015; Heijnes et al. 2018). Moreover, the results of previous studies confirm that learning gains are greater when students generate their own representations in general, as opposed to working with expert-generated representations (Kozma and Russell 2005; Wu and Puntambekar 2012). Student-generated representations have been used to evaluate students' understanding of scientific concepts (Hubber et al. 2010; Zhang and Linn 2011), to make connections with prior knowledge (Akaygun and Jones 2013), to identify conflicts among their ideas (Chi 2009), and to provide feedback about students' understanding (Stieff et al. 2005). They can help students to become more than just consumers of knowledge (Danish and Enyedy 2007), but active learners (DiSessa and Sherin 2000; Yaseen and Aubusson 2018). These advantages have been shown for a variety of student-generated representations, such as diagrams (Davidowitz et al. 2010; Gobert and Clement 1999), sketches (Quillin and Thomas 2015), animations (Nordin and Osman 2018), and simulations (Olde and de Jong 2004).

Focusing on student-generated animations, Hoban (2009) distinguishes three main forms: *hand-drawn*, *stop-motion*, and *computer-based* animation. Hand-drawn animations are based on students' own analog drawings. Stop-motion animation (SMA) involves taking digital still photographs of objects or pictures after they have been moved manually to simulate movement, and computer-based animation involves employing computer-generated images as the basis for the animation. Hoban and Nielsen (2013) argue that SMAs have two key advantages over the other kind of animations. Firstly, their inherent simplicity means that students can easily and quickly learn the technique. Secondly, it only requires

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ubiquitous technology such as a digital still camera and a computer in order to generate the illusion of motion. Moreover, since a SMA is created frame by frame and can be played in slow motion using a computer (Macdonald and Hoban 2009), students reported having enough time to grasp the underlying concepts (Hoban 2007).

From 2005 onwards, a sizable body of research has focused on the use of these student-generated SMAs in educational contexts (Brown et al. 2013; Ekici and Ekici 2014; Hoban and Nielsen 2014; Mills et al. 2018b; Wilkerson et al. 2018). However, no overview of this research is currently available. Also, the results on the *effectiveness* of the application of SMAs in education are inconsistent. This inconsistency can be attributed to a variety of causes, ranging from inadequate pedagogical understanding on how to integrate digital technology (Vratulis et al. 2011), lack of students' digital literacies (Paige et al. 2016), lack of students' argumentation and negotiation skills (Kidman and Hoban 2009), lack of students' representational literacies and higher-order thinking skills (Brown et al. 2013), and to the problem of cognitive load due to the use of SMAs for representing inappropriate science concepts (Kidman and Hoban 2009).

Therefore, the main objective of the current review is to systematically identify, critically analyze, and discuss scientific research on student-generated SMAs to enable educators to make the best use of SMAs in science classes. Besides, this review study also aims to highlight the research gaps, providing directions for future research in the field. In line with Noroozi et al. (2012), we employ *learning outcomes*, *learning processes*, *learning environment*, and *student prerequisites* (inspired by Biggs's (2003) 3P Model) as main categorical descriptions in this review study. This structure allows us to categorize available research findings at any educational level into sections that are relevant to both educators and science education researchers, highlighting both the main findings and main avenues for further research of the four components.

Therefore, based on the four components mentioned above, the following research questions are formulated to be answered in this study:

- RQ1. What research findings are available regarding the relationship between student-generated SMA and learning outcomes in science classes?
- RQ2. What research findings are available regarding learning processes involving student-generated SMAs?
- RQ3. What research findings are available on the learning environment prerequisites in relation to student-generated SMAs?
- RQ4. What research findings are available on the student prerequisites in relation to student-generated SMAs?

## Method

This work follows the systematic literature review protocol by Brereton et al. (2007). For this review, we adapted a narrative analysis (Van Dinther et al. 2011) approach identifying current trends and also practical implications of student-generated SMA as a learning approach in science classes from a holistic point of view, contributed by the adopted framework as our theoretical basis. The result of this narrative analysis will be more qualitative than quantitative, providing in-depth information about the topic under study (Dochy et al. 2003).

### Literature Search

Literature search was conducted on the following databases: Scopus, Web of Science (WoS), ERIC, Science Direct, and Google Scholar. We have limited the search to English publications with an available full-text version. The time span for the search was limited from 2005 through 2019. The last search was performed on August 10, 2019.

For selecting the most relevant keywords to the research scope, in a first step, we identified synonyms or related terms concerning SMA, and we found the terms Stop-action animation, Slow-motion animation, Slowmation, and flipbook-like animation. In the second step, we combined the related terms with the Boolean operators OR and the overlapping concept areas with AND to arrive at the following search string: *Learn\** OR *understand\** AND *physics* OR *chemistry* OR *biology* OR *Geology* OR *science* AND *Slowmation* OR *Slow-motion animation* OR *Stop-motion animation* OR *Stop-action animation* OR *Flipbook-like animation*. We composed the search string in each of the five databases manually based on the search functionality offered by that database.

### Criteria for Inclusion

The literature search and publication selection process is shown in Fig. 1. The initial search resulted in 29 papers in Scopus, 21 papers in WoS, 4 papers in ERIC, 51 papers in ScienceDirect, and 33 papers in Google scholar. Among the findings, 54 papers appeared to be duplicated. Then, five inclusion criteria were employed for screening the abstracts and collecting relevant studies:

1. The study investigated the stop-motion technique for generating an animation.
2. The SMA had to be generated by the students—at any level (e.g., from pre-elementary to tertiary education).
3. The study had to report quantitative and/or qualitative data.
4. The study had to be performed in science classes (i.e., physics, biology, chemistry, and geology).

**Fig. 1** Selection process
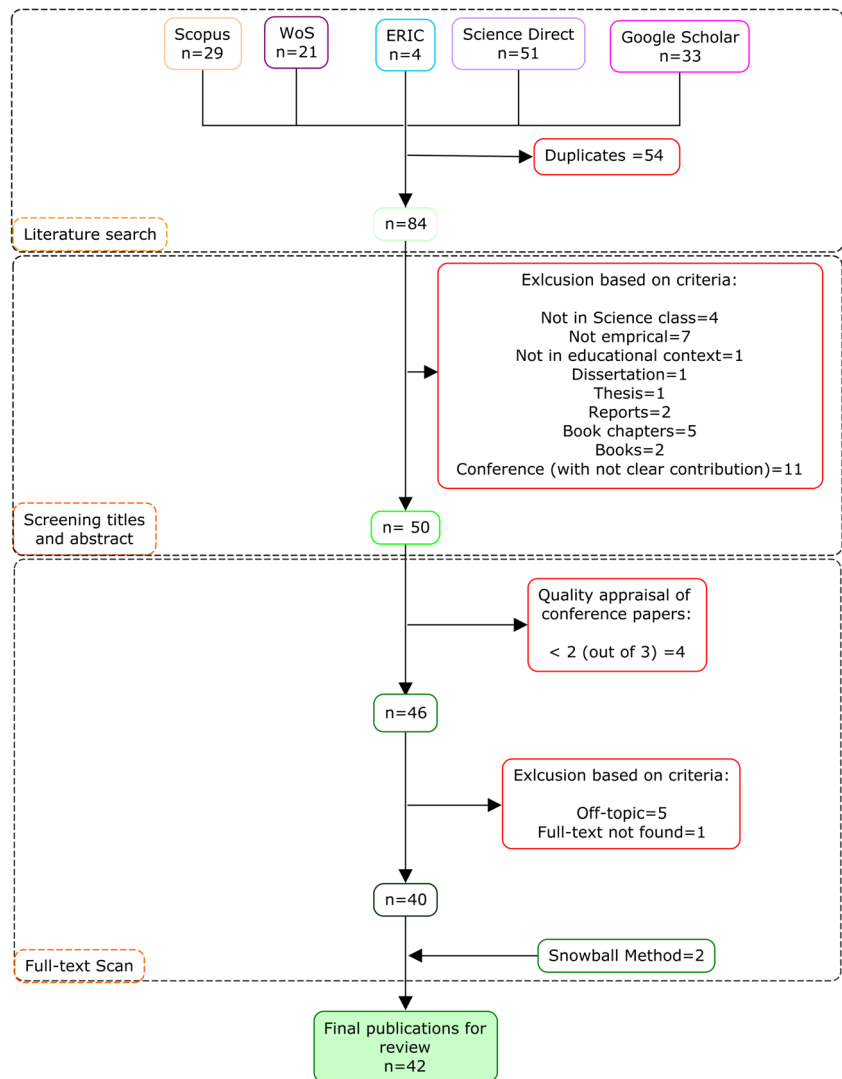


5. The study had to address educational purposes, e.g., learning outcomes, learning processes, design procedures of SMA in an educational context, and/or SMA as a teaching approach.

After reading the abstracts, 50 studies (37 peer-reviewed and 13 conference papers) remained for a full reading. Studies that did not meet one or more of the above criteria were excluded for analysis.

## Identification of Relevant Publications

In the next step, full texts were analyzed using the abovementioned inclusion criteria. Also, to ensure the quality of conference papers, we adopted criteria by Theelen et al. (2019) (p.19) for quality appraisal of qualitative and quantitative empirical studies. Among the 13 conference papers which had a clear contribution, four papers were excluded for further

review after quality appraisal (mean score below 2). Moreover, six other papers were excluded since they turned out to be off-topic or were not available full text. Also, snowballing the references of included articles yielded another two peer-reviewed studies. After reading the abstracts and full texts, both of them were included in the review.

Eventually, 42 publications were retained for the review, all pertaining to quantitative and/or qualitative empirical data on using the stop-motion technique for developing an animation in science classes. A complete list of reviewed publications is provided in Appendix 1 and is indicated by asterisks in the Reference section.

## The Quantitative Description of Scientific Research into Student-Generated SMAs

Figure 2 shows the number of papers published each year. The observed slight increase in recent years can be the result of the

**Fig. 2** Yearwise distribution of selected papers
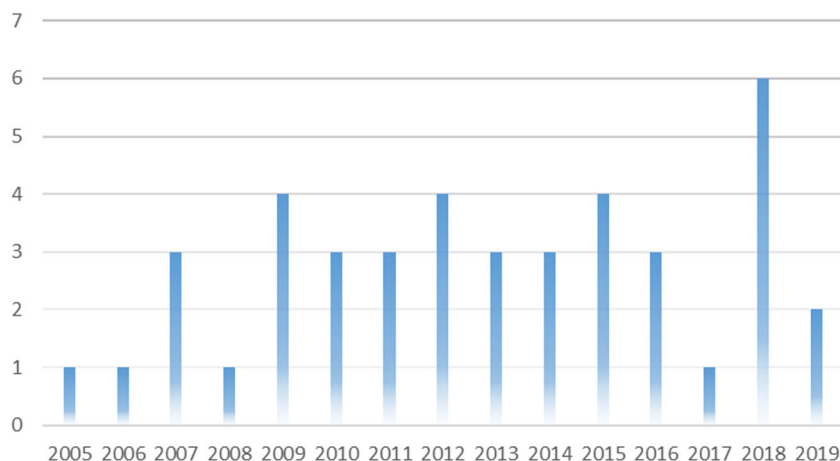


growing tendency toward technology-based learning environments in science classes (see Oliveira et al. 2019).

Twenty-eight of empirical studies (out of 42) used qualitative methods (e.g., surveys, interviews, and observations) to analyze student-generated SMA processes and outcomes; only six exclusively used quantitative methods. The remaining eight used both qualitative and quantitative methods (i.e., mixed method). Student-generated SMAs have been reported to be used in different science classes such as biology (14 publications), multi-domain (different science classes) (11), physics (9), chemistry (4), geology (2), and general science (2). The educational context of the empirical studies varied among undergraduate student teachers (24 publications), students in secondary (6), elementary (5), middle (4) schools, and multi-level (e.g., elementary, middle, and secondary) (2) and pre-elementary (1) students. Table 1 summarizes these quantitative results.

**Table 1** Quantitative data description of the reviewed papers

| Variables | Items | Number of publications | Percentage |
|---|---|---|---|
| Type of analysis | Qualitative | 28 | 66.7 |
| | Quantitative | 6 | 14.3 |
| | Mixed | 8 | 19.0 |
| Class (subject) | Biology | 14 | 33.3 |
| | Multi-domain | 11 | 26.2 |
| | Physics | 9 | 21.4 |
| | Chemistry | 4 | 9.5 |
| | Geology | 2 | 4.8 |
| | Science (general) | 2 | 4.8 |
| Educational level | Student teachers | 24 | 57.2 |
| | Secondary school | 6 | 14.3 |
| | Elementary school | 5 | 11.9 |
| | Middle school | 4 | 9.5 |
| | Multi-level | 2 | 4.7 |
| | Pre-elementary | 1 | 2.4 |

# Results

Following the structure of our research questions, we extracted the influential and constitutional factors of employing student-generated SMA as a teaching and learning approach in science classes from the reviewed publications and categorized them into four inter-related components: learning outcomes, learning process, learning environment, and student prerequisites.

## What Research Findings Are Available Regarding the Relationship Between Student-Generated SMA and Learning Outcomes in Science Classes?

In most studies, *cognitive* and *non-cognitive* learning outcomes were among the most frequently reported outcomes of using student-generated SMA in science classes. While cognitive learning outcomes are those knowledge-related attributes usually measured by students' overall GPA (Walker 2008) or exam scores (Shi et al. 2020), non-cognitive outcomes are generally viewed as attitudes, behaviors, and values (Levin 2012) that can contribute to students' educational performances (Wanzer et al. 2019).

Concerning the cognitive outcomes, many favorable results on *domain-specific knowledge* are reported in the reviewed papers. However, some studies showed inconclusive or neutral results. Also, an increase in motivation and engagement has been reported as *non-cognitive outcomes* of student-generated SMAs. Moreover, *domain-general skills* such as reasoning, collaboration, and digital literacy skills are generally reported to be positively influenced by the application of SMA. For the specific target group of student teachers, a remarkable outcome is that their *knowledge of instructional strategies* concerning the use of SMAs in science classes did not seem to develop.

**Cognitive Learning Outcomes** Several papers reported significant improvement in students' domain-specific knowledge

(Ekici et al. 2014; Hoban et al. 2009a; Jablonski et al. 2015; Macdonald and Hoban 2009; Wilkerson et al. 2015; Wishart 2017; Yaseen and Aubusson 2018). Also, according to the reviewed papers, student-generated SMAs facilitate conceptual understanding by revising mis- or alternative conceptions and improving students' mental models (Akaygun 2016; Brown et al. 2013; Church et al. 2007; Fleer and Hoban 2012; Hoban and Nielsen 2013, 2014; Keast et al. 2010; Kidman et al. 2012; Loughran et al. 2012; Mills et al. 2018a; Nielsen and Hoban 2015; Peter et al. 2011).

Neutral or conflicting results have also been reported. Chang et al. (2010) found that students' understanding of science concepts was better for students who only viewed the animation than the students who designed and developed their animation. Only when integrating peer-evaluation and designing, a significant improvement of students' learning was found. Peter et al. (2011) pointed out that there was no significant difference between students' conceptual understanding among SMA and paper sketch groups. Also, in Ekici et al.'s (2014) study, despite higher achievement scores for SMA generated groups immediately after the intervention, no statistical difference in retention test scores was found between control and experimental groups.

**Non-cognitive Learning Outcomes** The majority of studies that address non-cognitive learning outcomes report an improvement in motivation, engagement, and interest through the use of SMAs. The autonomy support that is implicit in allowing students to develop their own animations increases autonomous types of motivation and, eventually, engagement (Bogiages and Hitt 2008; Brown et al. 2013; Hoban 2005, 2007; Hoban and Nielsen 2010; Jablonski et al. 2015; Mills et al. 2018b; Peter et al. 2011; Wilkerson et al. 2015). Mills et al. (2018b) study reports differentiated findings in this respect. Despite an improvement in students' individual interest in learning geology, their maintained situational interest value, i.e., the belief that the content itself is meaningful to one's life beyond the classroom (Linnenbrink-Garcia et al. 2010), did not improve. Also, Church et al. (2007) claimed that generating a SMA concerning an event of interest in the student's life (i.e., connecting more closely with their personal lives) appears to improve their motivation and engagement better.

**Domain-General Knowledge and Skills** Wilkerson et al. (2018) reported that students' mechanistic reasoning skills could be elicited and improved by creating mechanistic models with a combination of multiple representations, i.e., drawing, SMA, and simulation. Berg et al.'s (2019) study illustrated that the SMA task enabled students to better engage in reasoning concerning both the macro (i.e., observable) and the sub-micro-level (i.e., a level that cannot be observed) models, and how they relate to each other. Nordin and Osman (2018) found that student-generated SMA can be effective in

fostering collaborative problem-solving skills in terms of establishing and maintaining shared understanding and group organization toward finding the appropriate action to solve a physics problem in secondary education. The results of some studies also revealed that the SMA task contributed to the development of twenty-first-century skills such as creativity, communication, and cooperation skills, information literacy, research skills, technology, and media literacy skills (Atalay and Belet Boyaci 2019; Karakoyun and Yapıcı 2018). Skills in using technology, such as taking photos with digital cameras, were also reported as an outcome of intentionally teaching using SMA in early childhood science classes (Fleer and Hoban 2012).

Researchers also noticed that their student teachers were able to further their abilities in many other areas aside from 'just science', including information and technology skills, creative writing, group work, and research (Keast et al. 2010; Kidman et al. 2012). Having student teachers create a narrated SMA to explain a science concept in Hoban and Nielsen's (2014) study provided a context for generating discussions, exchange, and clarification of ideas, which finally contributed to scientific reasoning skills.

**Knowledge of Instructional Strategies** Although research confirmed the possibility and the benefits of generating SMA as a teaching approach in science classes (Ekici and Ekici 2014; Fleer and Hoban 2012; Hoban et al. 2007; Keast et al. 2010; Loughran et al. 2012; Nielsen and Hoban 2015; Paige et al. 2016), Vratulis et al. (2011) stated that student teachers did not encourage their pupils to design and make SMA projects in practice—despite the student-centered approach advocated during the program. Therefore, knowledge and beliefs about instructional strategies for teaching science as one of the main elements of Magnusson et al.'s (1999) pedagogical content knowledge model, did not improve in this study. Vratulis et al. (2011) concluded that introducing student teachers to alternate instructional strategies employing digital technology as learners in a teacher education program in itself is not enough for them to deploy these technologies in their schools.

## What Research Findings Are Available Regarding Learning Processes Involving Student-Generated SMAs?

The *learning process* involving SMA turns out to be cyclical rather than linear. Both surface and deep learning are encountered in the studies on SMA, depending on the amount of scaffolding provided. The *learning activities* such as class discourse about the generated SMAs and peer-evaluation bring to the fore students' sometimes conflicting ideas and thus stimulates deeper learning. Moreover, putting narration on the generated SMA can provoke a better understanding of the subject matter. Several *scaffolding techniques*, such as

presenting general strategies, asking questions, and the use of expert representations, are reported.

**Learning Process** In order to improve learning in any learning environment, it is important to understand students' learning processes (Beyaztaş and Senemoğlu 2015). The more instructors understand this process, the better their chance of meeting the diverse learning needs and scaffolding their students' learning (Felder and Brent 2005). In this line, Kidman (2015) distinguishes *first-* and *second-order learning* in the context of the process of generating SMAs. First-order learning refers to considering only observable characteristics of the phenomena, with very little analysis of the visual representation to be made. Second-order learning (or deep learning) emerges once the learner engages in the science content behind the phenomenon. Here, the learner mentally engages with prior knowledge, the new information provided in published sources, and the information interpretation provided by group participants. The learner makes meaning of all this information and then re-represents the new findings in a SMA.

Hoban et al. (2009b) observe that the learning pathway in the SMA learning approach is cyclical, iterative, and dynamic rather than linear. This *recursive checking of information* was clearly manifested in Hoban et al.'s (2011) study when students referred back to the support material and discussed it with their peers. Also, according to Kidman et al.'s (2012) observations, in a collaborative setting, groups can choose to superficially accept one representation of the chunks (i.e., surface learning) or through discussion and planning agree by consensus on the key "chunks" that need to go in their SMA (i.e., deep learning). According to scholars, this iterative process is responsible for revealing and revisiting students' misconceptions (Hoban et al. 2009b; Hoban and Nielsen 2013) and encouraging their conceptual learning (Hoban et al. 2011).

**Learning Activities** According to Wilkerson et al. (2015), intentionally letting students generate and evaluate knowledge, e.g., asking them to construct a model and share their product individually, will help them to both realize the wealth of knowledge they already have about the subject and evaluate that knowledge. Moreover, scholars reported that asking students to share their final products can also bring their conflicting ideas and uncertainties about the science concept to the fore (Mills et al. 2018a), leading to a substantive discourse in the classroom (Brown et al. 2013). This discourse, especially in the form of *peer-evaluation*, can effectively improve the accuracy of the representations (Hoban and Nielsen 2014) and contribute to students' conceptual learning (Chang et al. 2010; Mills et al. 2018a) and student teachers' better mastery of subject matter (Hoban and Nielsen 2013). In this regard, Kamp and Deaton (2013) reported that providing a rubric for students' peer-evaluation could support the evaluation process

of final student-generated SMAs. Also, Hoban and Nielsen (2013) claimed that clear explanation as a narration in the final representation provoked the student teachers' better realization of subject matter.

**Scaffolding Techniques** In their study with 28 elementary school students, Wilkerson et al. (2018) found that groups struggling to construct a model progressed when they received guidance about *general modeling strategies* (i.e., rules and constraints for making a model), but not when they received guidance about *model content*. They claim that in terms of complex systems reasoning, students benefit from explicit support in considering the elements, behavior, and interactions in a system both before and during the exploration and construction of models. Their findings also highlight that an iterative modeling activity across multiple representations (drawing, SMA, and simulation) can facilitate and deepen student learning and engagement.

According to Nielsen and Hoban's (2015) study, *expert's representations* can scaffold students' understanding while students discuss their own representations. In the same line, Yaseen and Aubusson (2018) claim that teachers can ask students to identify, discuss, explain, and map the similarities and differences between student- and expert- generated animations. They reported that with this sort of mediation, conceptual learning was improved more than if the students had only viewed the experts' animations.

Also, *asking questions* by the teacher is highlighted in some papers as a way to scaffold students "learning toward the science part of the animation during the developing process of a SMA" (Mills et al. 2018a; Wilkerson et al. 2015; Yaseen and Aubusson 2018). In Yaseen and Aubusson (2018)'s study, students focused on the technical quality of animation, but the teacher took the discussion beyond this, by asking students to consider the scientific propositions implicit in the animations. These guiding questions helped the students to both understand and explain the exact science concepts related to the subject of their SMA. Also, they claim that teachers can enhance students' critical thinking by asking why their SMA might be inadequate and how it could be improved and by showing them other ways of looking at a specific concept. Similarly, Mills et al. (2018a) reported that teachers' questions to encourage thinking and provoke scientific explanations were crucial in revising students' conflicting ideas and developing conceptual understanding.

## What Research Findings Are Available on the Learning Environment Prerequisites in Relation to Student-Generated SMAs?

The findings suggest that *the science concept* needed to be presented as a SMA by students should be self-contained, dynamic in nature, and not too difficult to represent. As for

*software and hardware*, most studies employ generic software, and this is sometimes claimed to be an essential prerequisite. There are, however, several studies based on software developed specifically for the creation of SMAs. A *collaborative setting* is chosen in almost all studies since discourse during the process of constructing an SMA is considered to be of prime importance for more in-depth learning.

**Characteristics of the Science Concept** Keast et al. (2010) found that the SMA approach was shown to be most effective when it used to present a science concept which is small, self-contained, and easy to chunk and represent. Peter et al. (2011) reported that student-generated SMA improves learning, especially for content that involves dynamic events, e.g., moon phase, cellular division, or smell diffusion. In terms of cognitive load, Kidman and Hoban (2009) claimed that when a topic requires a considerable representation effort (such as the fiddly detail in the representation of chromosome mapping), cognitive load focuses on the representation, rather than scientific processes.

**Software and Hardware** Hoban et al. (2011) claimed that a key feature of generating a SMA is that it does not involve the use of any specific software. In most of the studies, learners used generic software such as Apple's QuickTime Pro (Hoban 2005; Hoban and Ferry 2006; Vratulis et al. 2011), Windows Movie Maker (Jablonski et al. 2015; Nordin and Osman 2018; Wishart 2016), SAM animation (Church et al. 2007; Hoban et al. 2009a; Hoban and Nielsen 2013; Wilkerson et al. 2015) and mobile apps like MyCreate (Mills et al. 2018b), iMotionHD (Wishart 2017), and iStopMotion (Berg et al. 2019; Kamp and Deaton 2013).

In some studies, however, domain-specific software was used to develop student-generated SMAs. For example, Chang et al. (2010) used "Chemation" for making a molecular SMA in Chemistry. Akaygun (2016) used "ChemSense" which is specifically designed to generate drawings and animations for chemistry concepts through a stop-motion technique. Yaseen and Aubusson (2018) used K-Sketch for generating SMAs about different states of matter by students. Akaygun (2016) also suggested that participants in K-Sketch produced their animations faster and had a significantly lower cognitive load than common animation software, such as ChemSense, with which it was compared. Also, according to his findings, K-Sketch provides the most freedom for representing dynamics, and ChemSense provides more options for representing structural features. SiMSAM (Simulation, Measurement, and Stop-Action Moviemaking) allows students to create SMAs by using an external camera to capture successive photos of drawings or craft materials and was used in different studies by Wilkerson et al. (2015, 2018). This software was designed specifically to support learners in "discovering" aspects of kinetic molecular theory.

**Setting: Collaborative/Individual** Most of the empirical research in the domain of student-generated SMAs have been performed in a collaborative setting (Brown et al. 2013; Jablonski et al. 2015; Mills et al. 2018a; Vratulis et al. 2011; Wilkerson et al. 2015, 2018; Wishart 2016, 2017; Yaseen and Aubusson 2018). Many researchers argued that generating discussion is the main benefit of student-generated SMAs in collaborative settings. Brown et al. (2013) claim that the collaborative creation of a SMA facilitates rich opportunities for students to use discourse as a representational form to generate and mediate between other representational forms. Their findings are in line with Hoban and Nielsen's (2014) study, which suggests having student teachers create a narrated animation in order to explain science, the narrative sparking subsequent discussion. Loughran et al. (2012) found that collaborating with peers in developing SMAs helped student teachers recognize and respond to a range of pre- or alternative conceptions that they held, not only in terms of pre-conceptions' nature but also in terms of their origin and possible address in the classroom.

According to Wishart (2016, 2017), group discussions were found to be key to student science learning through the co-construction of meaning. In the same line, Kidman (2015) asserted that SMA, when used in a collaborative inquiry-based learning context, is a technique in which "the new 'meaning-making' of the designers facilitates the new 'meaning-making' of others." Paige et al.'s (2016) study with science student teachers showed that working in a collaborative setting was preferred to an individual setting by the students.

## What Research Findings Are Available on the Student Prerequisites in Relation to Student-Generated SMAs?

SMA can be used at all *age* levels from pre-school to university, an important subset of studies (24 out of 42) pertaining to student teachers. There are conflicting results on the importance of *prior knowledge* for the construction of a SMA. *Digital literacy*, however, does appear to be an important factor.

**Age** The main trend is that SMA can be applied to almost all age levels, from early childhood to university classrooms (Hoban and Nielsen 2014). Studies include 4-year olds learning science concepts (Fleer and Hoban 2012), elementary classes co-constructing spinning in space through collaborative generating of a SMA (Brown et al. 2013), and smell diffusion by grade 6 students through multimodal representation, including SMA (Wilkerson et al. 2015).

On the middle school level, more studies with SMA have been performed (e.g., Jablonski et al. 2015; Mills et al. 2018a; Mills et al. 2018b). The same holds for secondary school classrooms (e.g., Church et al. 2007; Kamp and Deaton 2013). In the context of university teacher education

programs, there have been many studies (24 out of 42) on how creating a SMA influenced student teachers in learning various science concepts (Berg et al. 2019; Hoban et al. 2009a; Hoban and Nielsen 2012, 2013), pedagogical intent (Hoban et al. 2007; Hoban and Ferry 2006; Keast et al. 2010; Nielsen and Hoban 2015), and technological pedagogical content knowledge (Paige et al. 2016). Finally, Wishart (2016), in a multi-level study (primary, middle, and secondary school), found that students of different ages can benefit from generating SMA in science classes. She found that the younger students (aged 8–9) most often enjoyed *making*, whereas the older ones (aged 15–16) most enjoyed *seeing* their finished results.

**Prior Knowledge** Kidman et al. (2012) compared learning processes in student-generated SMAs with Peirce's (1955) model of semiotic systems and claimed that students 'prior knowledge serves as a "referent" in this system, and it is important for starting the cumulative semiotic progression responsible for learning through generating SMA. As learners revisit their prior knowledge through different semiotic systems during design and development, building from one representation to the next promotes learning (Nielsen and Hoban 2015). However, Hoban and Nielsen (2013) found that the process of creating a SMA was effective even if students (pre-school children) did not have any prior knowledge about the domain. This finding is in line with Church et al. (2007) and Mills et al. (2018a), who found that the SMA task induced higher cognitive activity and led students to critically examine their own mental models even in the absence of prior instruction.

**Digital Literacies** Paige et al. (2016) found that learners who were novices in digital literacies had difficulties accessing basic digital technology and equipment, impeding their construction of a SMA. This finding supports the general importance of improving ICT skills in a cross-curricular fashion. Brown et al. (2013) claim that explicit teaching of representational literacies, i.e., to effectively communicate ideas using multimedia (Flood et al. 2004), could be beneficial in this respect.

## Discussion and Conclusions

Overall, the reviewed papers agree that engaging in designing and developing a SMA can facilitate the acquisition of different domain-specific/general knowledge and skills as well as non-cognitive learning outcomes in different scientific contexts. However, studies report varying and sometimes conflicting results on students' conceptual learning (Chang et al. 2010; Peter et al. 2011), retention (Ekici et al. 2014), interest (Mills et al. 2018b), and student teachers' knowledge of instructional strategies development (e.g., Vratulis et al. 2011).

Regarding the latter, a striking finding was that student teachers did not start to use SMA in their own classes, indicating that their knowledge of instructional strategies had not matured.

The central focus of reviewed papers is on learning processes and activities in student-generated SMAs, pertaining to surface and deep learning processes and scaffolding techniques toward specific learning activities. Peer-evaluation and adding narration stand out as activities that can improve the learning outcomes of student-generated SMAs. Deep learning during the generation of a SMA does not happen automatically (Kidman 2015; Kidman et al. 2012), and it needs scaffolding techniques in the form of:

(1) explicit support in considering elements, behaviors, and both before and during the construction of the SMAs (Wilkerson et al. 2018);

(2) discourse on similarities and differences between student- and expert-generated animations (Nielsen and Hoban 2015; Yaseen and Aubusson 2018);

(3) teachers' questions highlighting the science aspects of the animation, provoking students' critical thinking (Mills et al. 2018a; Wilkerson et al. 2018; Yaseen and Aubusson 2018);

(4) teaching the modes of discourse and the skills for classroom discussion and collaborative learning (Brown et al. 2013); and

(5) providing rubrics for peer-evaluation (Kamp and Deaton 2013).

Some of the findings are in line with other studies in the field of modeling-based learning. For example, in comparing student- and expert- generated animations, it was found that a discussion on the (mis)match between animations and target phenomenon may be more valuable to students' learning than the development of a more accurate animation per se (Aubusson et al. 2009). Yaseen and Aubusson (2018) argued that the errors and imperfections in student-generated SMAs create a locus for learning. Their findings also support the idea that relatively weak student-generated animations can be better stimuli for students' learning than expert animations.

There is a small but growing body of research focusing on learning environment prerequisites for using student-generated SMAs, in terms of resources and settings. The consensus among researchers is that the science concept which is used for developing a SMA should be small, self-contained, and easy to chunk and represent dynamic events, preferably related to learners' daily life. A plausible explanation is that a highly complex topic adversely influences the learning task by requiring a great effort in the actual representation. This can take attention away from the scientific process or concept.

In most of the studies, learners designed and developed SMAs in a collaborative setting. Findings reveal that the

construction process encourages a practice of collaborative learning and requires that students negotiate what content to include and how to represent their ideas in multiple modalities. Brown et al. (2013) demonstrate that the use of SMA techniques prompted students to work cooperatively and develop their cooperation skills.

Although many researchers argued that having prior domain knowledge is crucial for starting the cumulative semiotic progression in generating a SMA, Macdonald and Hoban (2009) found that prior knowledge is not predictive for the results of a knowledge post-test. This result can be interpreted by referring to the design procedure of a SMA, that in the first step, students are needed to enrich their content knowledge about a given science concept. Thus, this initial step helps them to acquire needed knowledge for building the SMA.

## Implications for Research and Practice

In our review, the qualitative studies outnumber the quantitative ones, which indicates a further need for quantitative research in the field. As qualitative research on pedagogical effects of student-generated SMAs in science classes dominates the field so far, several researchers recommend (quasi-)experimental designs to generate data to compare the learning outcomes with those of other forms of instruction, such as direct instruction or constructivist approaches (Hoban et al. 2011; Hoban and Nielsen 2013, 2014).

While there has been much mention of both personality and cognitive factors relating to learning with external representations (see ChanLin 2001; Klein 2003), no research has been found to assess or control for these factors in student-generated SMA. For example, many researchers argued that spatial ability is crucial for any modeling activity, especially when students are engaged with dynamic and static visualization (Höffler 2010; Sudatha et al. 2018). Spatial ability is defined as the ability of "thinking about the shapes and arrangements of objects in space and about spatial processes, such as the deformation of objects, and the movement of objects and other entities through space" (Marunic and Glazar 2014). Mayer (1994) found that students with lower spatial ability have difficulties processing and profiting from the animations, and students with higher spatial ability profit from such animations. Although Nielsen and Hoban (2015) referred to spatial ability as a critical factor for generating SMA, none of the studies in this review considered and controlled for this ability. Therefore, it is recommended to conduct quantitative studies controlling for spatial ability as well as other personality and cognitive factors.

Some studies suggest working with multiple ages, genders, and cultural influences to examine social factors in using SMAs in the classroom (Church et al. 2007), or to repeat the study with a range of learners such as student teachers and different levels of students in general (Hoban et al. 2011). Also, with regard to the collaborative settings, future research has to take into account crucial factors such as group composition (Wishart 2017), demographic population, and group size (Brown et al. 2013).

Most of the studies conducted so far have focused mainly on pre and post data collection and not on data collection during the actual development process. In this regard, Yore and Treagust (2006) state that there have been few studies to investigate the "enhanced cognition that occurs during the transformation from one representation to another representation or one mode to another" (p. 208). Therefore, there is a need for further research on learning outcomes, and on the nature of the learning process, how that learning develops both in and between the different stages of creating a SMA. This will improve the understanding of how each representation or mode influences learning, especially in relation to the proposed educational affordance (Hoban et al. 2009a; Hoban and Nielsen 2010, 2012; Wishart 2016).

Although some research has been done on teacher practices and instructional strategies of successful implementation of SMA, there is a need for more research focusing on the role of the teacher in supporting student learning with this modeling technique (Chang et al. 2010).

Last but not least, teachers and researchers should pay close attention to the different learning pathways (i.e., deep vs. superficial learning). Since it is quite common and easy for the students to take the surface learning pathway, teachers should employ different scaffolding techniques such as guidance about general modeling strategies, showing expert-generated animations, asking questions, and providing a rubric for peer-evaluation in order to elicit deeper learning.

## Compliance with Ethical Standards

# Appendix

**Table 2** Overview of the various characteristics of the reviewed empirical publications (alphabetically ordered)

| Author(s) | Year | Journal | Research type | Participant | Target group | Domain | Software | Outcomes |
|---|---|---|---|---|---|---|---|---|
| Akaygun | 2016 | Chemistry Education Research and Practice* | Mixed | 523 | S | Chemistry | ChemSense and K-Sketch | Effectively revealed students' prior knowledge, an important tool for investigating students' mental models, helps learners to improve their understanding. |
| Atalay and Belet Boyacı | 2019 | International Electronic Journal of Elementary Education* | Mixed | 9 | E | Science | - | In SMA production process, students utilize and, in the process, develop creativity and innovation, critical thinking and problem solving, collaboration, and communication skills. |
| Berg et al. | 2019 | Chemistry Education Research and Practice* | Qualitative | 37 | S-T | Chemistry | IStopmotion for iPad | The SMA task enabled students to engage in reasoning concerning both the observations and the sub-micro-level models and how they relate to each other. |
| Bogiages and Hitt | 2008 | The Science Teacher* | Qualitative | - | S | Biology | Slideshow software | Highly engaging, increase students' interest, and a more in-depth understanding of the content. |
| Brown et al. | 2013 | Teaching Science: Australian Science Teachers Journal* | Qualitative | 16 | E | Physics | - | The social construction of knowledge, fostering substantive discourse, scientific literacy, and engagement. |
| Chang et al. | 2010 | Journal of Science Education* | Quantitative | 271 | M | Chemistry | Chemation | Designing animations, coupled with *peer evaluation*, is effective at improving *student learning* with instructional animation. |
| Church et al. | 2007 | International Journal of Engineering Education* | Qualitative | - | S | Physics | SAM animation | Deeper reflection, conceptual understanding, representations of mental models, revealing the preconceptions, and stimulate discussion. |
| Ekici and Ekici | 2014 | European Journal of Social Sciences Education and Research* | Qualitative | 49 | S-T | Biology | Windows Movie Maker/SAM animation | **Pros:** Facilitates learning, increases creativity, self-confidence, attendance to the lesson, cooperation awareness, and technological ability. **Cons:** Time consuming and the process is troublesome. |
| Ekici et al. | 2014 | The Eurasia Proceedings of Educational & Social Sciences | Quantitative | 83 | S-T | Biology | Windows Movie Maker/SAM animation | Positive influence on students' learning. No effect on retention. |
| Fleer and Hoban | 2012 | Australasian Journal of Early Childhood* | Qualitative | 25 | P-E | Multi-domain** | Windows Movie Maker/SAM animation | Enacts Intentional teaching, stimulate discussion, provides a sense of purpose for exploring scientific concepts and conceptual development of the child, and scientific self-awareness. |
| Hoban | 2005 | Teaching Science: Australian Science Teachers Journal* | Qualitative | 24 | S-T | Biology | QuickTime Pro | Seven steps procedure improves students' engagement in science lessons. |
| Hoban | 2007 | Contemporary Issues in Technology and Teacher Education* | Qualitative | 10 | S-T | Multi-domain | QuickTime Pro/iStopMotion | Introducing four Phases of developing a Slowmation, generates an authentic "need to know," engagement, and a real purpose of understanding. |
| | 2006 | | Qualitative | 2 | S-T | Biology | QuickTime Pro | |

**Table 2** (continued)

| Author(s) | Year | Journal | Research type | Participant | Target group | Domain | Software | Outcomes |
|---|---|---|---|---|---|---|---|---|
| Hoban and Ferry | | Proceedings of the 2006 World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education | | | | | | Six steps designing procedures, adoptable for school contexts. |
| Hoban and Nielsen | 2010 | Teaching Science: Australian Science Teachers Journal* | Qualitative | – | E | Biology | – | Introducing 5Rs designing approach, promote learning and engagement in learning |
| Hoban and Nielsen | 2012 | Research in Science Education Journal* | Qualitative | 24 | S-T | Multi-domain | Windows Movie Maker/SAM animation | Serves as an explanatory resource, promotes discussion about alternative conceptions, collective sharing, and inquiry. |
| Hoban and Nielsen | 2013 | International Journal of Science Education * | Qualitative | 3 | S-T | Biology | Windows Movie Maker/SAM animation | Fosters a cumulative semiotic progression, promotes learning, encourages conceptual change, revises alternative conceptions, and provides social interaction. |
| Hoban and Nielsen | 2014 | Journal of Teaching and Teacher Education* | Qualitative | 3 | S-T | Physics | Windows Movie Maker/SAM animation | Promotes discussion through four key affordances, facilitates scientific reasoning, and resolving alternative conceptions. |
| Hoban et al. | 2007 | Proceedings of the 2007 Australian Teacher Education Association National Conference | Qualitative | 10 | S-T | Multi-domain | QuickTime Pro | *Pros*: Widespread use in different classes (science, Math, Social science...) *Cons*: Crowded curriculum, time constraints, access to technology, and classroom management are the most difficulties. |
| Hoban et al. | 2009a | Proceeding of World Conference on Educational Multimedia, Hypermedia and Telecommunications | Qualitative | 29 | S-T | Multi-domain | SAM animation | Increases in knowledge during the creation phase and review phase. |
| Hoban et al. | 2009b | Proceedings of The Future of Learning Designs Conference- University of Wollongong | Qualitative | 3 | S-T | Biology | - | Influences from multiple modes of representing the content at each phase. The actual learning process is much more dynamic and iterative with social interaction in all phases. |
| Hoban et al. | 2011 | Journal of Research in Science Teaching* | Qualitative | 3 | S-T | Biology | QuickTime Pro | Progression of meaning in the 5Rs model is not strictly linear, includes recursive checking of information, final artifact illuminates alternative conceptions. |
| Jablonski et al. | 2015 | The Journal of the Pacific Circle Consortium for Education* | Quantitative | 100 | M | Biology | Windows Movie Maker | Improves learning, provides collaborative learning, promotes sharing of information, and has a motivational effect. |
| Kamp and Deaton | 2013 | Journal of science activities* | Qualitative | - | S | Biology | iStopMotion (iPad) | Enjoyable, promote learning and addresses Next Generation Science Standards (NGSS) |
| Karakoyun and Yapici | 2018 | International Education Studies* | Qualitative | 12 | S-T | Biology | Stopmotion Studio (mobile app) | Development of the twenty-first century skills such as creativity, communication and cooperation skills, information literacy and research skills, and technology and media literacy skills. |

**Table 2** (continued)

| Author(s) | Year | Journal | Research type | Participant | Target group | Domain | Software | Outcomes |
|---|---|---|---|---|---|---|---|---|
| Keast et al. | 2010 | Brunei International Journal of Science and Mathematics Education | Qualitative | 72 | S-T | Multi-domain | - | Identifies alternative conceptions, works best in a series of lessons, most effective with small, self-contained, and easy to chunk and represents concepts, promotes computer skills, creative writing, group work; and, research. |
| Kidman | 2015 | Procedia - Social and Behavioral Sciences* | Mixed | 26 | S-T | Multi-domain | - | A conceptual shift of using ICT's for learning science rather than for doing science facilitates transformative learning and epistemic change through collaborative inquiry. |
| Kidman and Hoban | 2009 | Proceeding of NARST annual international conference (Grand Challenges and Great Opportunities in Science Education) * | Qualitative | 8 | M-L | Biology | - | Stimulates self-generated questions and meaning arises the need for attention to detail, the complexity of the topic affects the nature of questions, topics with greater representation effort causes cognitive load which leads to focus on the representation, rather than scientific content. |
| Kidman et al. | 2012 | Proceedings of 2nd International STEM in Education Conference. | Qualitative | 55 | S-T | Biology | - | Deeper conceptual and pedagogical learning through small groups of learners, Deeper learning will not occur unless there is this recursive checking of information, Conceptual change may be evident as a cause of dissatisfaction about the representation of a concept. |
| Loughran et al. | 2012 | Asia-Pacific Forum on Science Learning and Teaching* | Qualitative | 5 | S-T | Multi-domain | - | It provides the opportunity for seeing into learners' alternative conceptions, which creates multiple opportunities for pedagogical responses. |
| Macdonald and Hoban | 2009 | The International Journal of Learning* | Mixed | 14 | S-T | Physics | QuickTime pro | Science content knowledge is increased in the process of creating, peer, or content expert review and modifying. |
| Mills et al. | 2018a | Research in Science Education* | Mixed | 95 | M | Geology | MyCreate (iPad app) | Provides opportunities to work and learn in active, hands-on and collaborative ways; to exercise creativity; and to engage with technology, increases triggered the situational interest, maintained situational interest feeling and individual interest in learning science. |
| Mills et al. | 2018b | Journal of Science Education and Technology* | Mixed | 52 | M | Geology | MyCreate (iPad app) | Enhances students' conceptual understanding by increasing scientific conceptions and decreasing in alternative conceptions. It affords teachable moments that addressed students' conflicting ideas. |
| Nordin and Osman | 2018 | Journal of Education in Science, Environment and Health* | Quantitative | 70 | S | Physics | Windows Movie Maker | Effective in inculcating collaborative problem-solving skills among the students |
| Nielsen and Hoban | 2015 | Journal of Research in Science Teaching* | Qualitative | 3 | S-T | Physics | - | Increase the number of elements underpinning their understanding of subject matter, improve learning by |

   

**Table 2** (continued)

| Author(s) | Year | Journal | Research type | Participant | Target group | Domain | Software | Outcomes |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | generating self-explanation, provide the opportunity to articulate and challenge their prior conceptions. |
| Paige et al. | 2016 | Australian Journal of Teacher Education* | Quantitative | 31 | S-T | Science | iPhone/iPads app | Enhancing conceptual understanding, provide authentic, rich and creative opportunities for novice teachers to engage in a rigorous form of twenty-first-century skills, such as ways of thinking, ways of working, and tools for working, |
| Peter et al. | 2011 | Proceeding of EdMedia + Innovate Learning Conference | Quantitative | 171 | S-T | Physics | - | Improving conceptual understanding by reducing student misconceptions, significantly higher mean motivational scores than Paper Sketch group. |
| Vratulis et al. | 2011 | Journal of Teaching and Teacher Education* | Qualitative | 35 | S-T | Multi-domain | QuickTime Pro | Designing and developing Slowmation as a disruptive pedagogy serves as an instructional resource, student teachers did not encourage their pupils to design and make Slowmation projects. |
| Wilkerson et al. | 2015 | Journal of Science Education and Technology* | Qualitative | 5 | E | Physics | SiMSAM | Iterative modeling activity across multiple representational technologies (drawing, Slowmation, and simulation) can sustain and deepen student learning and engagement. |
| Wilkerson et al. | 2018 | International Journal of the Learning Sciences* | Qualitative | 28 | E | Physics | SiMSAM | Groups that developed increasingly mechanistic, explanatory models focused on elements, movement, and interactions (namely epistemic game) during multiple representations, i.e., drawing, Slowmation, and simulation. |
| Wishart | 2016 | School Science Review* | Mixed | 90 | M-L | Multi-domain | Windows Movie maker/PowerPoint/Flip-video cameras | Watching other students' finished animation motivates most of the students to learn science. The discussion was perceived by students to support their understanding. |
| Wishart | 2017 | Journal of Research on Technology in Education* | Qualitative | 15 | S-T | Multi-domain | Windows Movie maker/iMotionHD | The opportunities created for discussion, both with peers and teacher-led, are the most likely to promote learning. |
| Yaseen and Aubusson | 2018 | Journal of Research in Science Education* | Mixed | 28 | S | Chemistry | K-Sketch | The students improved their conceptual understanding through developing an animation, peer-discussion, and comparing their animations with expert-generated ones. |

*P-E* pre-elementary, *E* elementary school, *M* middle school, *S* secondary school, *S-T* student teacher, *M-L* multi-level

*Peer-reviewed Journals

**Multi-domain includes different science domains

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